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Pavement Management Applications in Central Massachusetts

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Rutland Department of Public Works
Woodlands Village at Hickory Hills Lake

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Abstract

This project analyzed the roadways in Rutland, Massachusetts and Woodlands Village in Lunenburg, Massachusetts. Both communities had similar constraints and aspirations of improving their road networks. The team provided recommendations to each sponsor to systematically and cost-effectively manage their roads. The team recommended the pavement management software PAVER to Rutland and developed a pavement management plan for Woodlands. If both sponsors consider the recommendations, the team predicts they will see the long-term benefits of effectively managing their road networks.

Acknowledgments

The project team would like to thank the project advisor Professor Suzanne LePage for her guidance and support throughout the duration of this project. The team would also like to thank the two sponsors; Gary Kellaher and Joseph Buckley from the town of Rutland, Massachusetts and John Brush, Bob Pease and Ed Werner from the Woodlands Village for their feedback and participation throughout the project.

Capstone Design

This project focused on the pavement assessment and repair of the roadways in Rutland, Massachusetts and the Woodlands Village Condominium Complex in Lunenburg, Massachusetts. The Woodlands Complex had no pavement management system and conducted road maintenance once a year with an outside contractor. The town of Rutland had a very basic form of pavement management, that consisted of the former Department of Public Works director, Gary Kellaher analyzing roads throughout the year and choosing the roads that he felt needed immediate repair. These two communities are worried for the future conditions of their roads, repair costs and want to develop a plan to help improve and protect them for the future.

The team analyzed multiple pavement management systems to help find the right tool for our two unique sponsors. The two sponsors had very different road networks and needs; this led to two different solutions to their problems. The team identified a pavement management software that satisfied both of the sponsor's needs for this project. From the team's research and the data, the pavement management software provided, the team created technical memorandums with recommendations specific to each sponsor. The recommendation for Woodlands included a repair solution, roadway analysis, cost estimate and a cross-sectional design. The recommendation for the Town of Rutland included a possible recommendation for pavement management software and analysis of a portion of the town's road network.

During the project, the design constraints factored into the final recommendations for each sponsor were:

Economic

When analyzing the recommended solutions for Woodlands Condominium Complex, their yearly maintenance allocations and roadway expenses were considered. The recommendations propose two options of with different financial costs, both of which are financially feasible for the community to execute. This is outlined in the cost estimate developed by the project team.

When developing the recommendation for the town of Rutland, MA, the team considered their yearly budget from the Chapter 90 program. The recommendation provides an economically reasonable solution tailored to their needs.

Environmental

The roadway repair recommended to the Woodlands Condominium Complex will have a minimal impact on the environment and the surrounding wetlands. The recommended repair will improve the road network. The software recommendation to the town of Rutland, MA will have no impact on the environment.

Social

The Woodlands Complex is a condominium development; therefore, the project identifies and address the needs of the community as a whole. The final recommendations were presented in front of the Board of Trustees and community members. This created a forum for the Trustees and community to make an informed decision moving forward.

The town of Rutland MA roadways are overseen by the Department of Public Works (DPW). During the project the DPW director changed. Despite the change, the project team ensured that the new director was aware and informed of our project and its goals.

Political

The Woodlands Condominium Complex is governed by a Board of Trustees. Throughout the project the team-maintained contact with several members to ensure they were well informed. These members provided vital financial information that was used to develop the recommendations.

The town of Rutland MA is government by a town administrator. However, the roadways and their repairs are overseen by the DPW. The DPW director controls how the allocated funding is used. Using the budget information provided the team developed a recommendation that allows the director to make cost-effective decisions.

Ethical

This project did not involve any tasks that would compromise the ethicality of any parties involved in the project. The team did not engage in activities considered to be dishonest and conducted no actions that would jeopardize any members of the Woodlands Condominium Complex, Rutland MA, or Worcester Polytechnic Institute communities.

Health and Safety

All recommended solutions of the project have been proven to be safe and will have no significant impact on the environment. The solutions will improve the road networks promoting a safe living environment.

Constructability

The solutions recommended by the project team consider the constructability of the solution. The decisions made were determined to be the best for both communities based on cost, community impact, and overall amount of construction. The team believes that these solutions are the most feasible for both communities.

Sustainability

All of the project team's solutions were justified by their longevity. The roadway repair will have a lasting impact on the road network and prolong the need for future repair. The software recommendation for the town of Rutland, MA will allow the DPW director to make cost-effective and impactful decisions to improve the road network.

Professional Licensure

Professional engineers have a large influence on the world because of the impact properly designed projects have. Obtaining a professional engineering license comes with the responsibility of safeguarding the health and well-being of the community and its members.

To qualify for a professional engineering license, one must first graduate from an ABET-accredited engineering school and pass the fundamentals of engineering exam. After four years of experience working under the direction of a PE one is eligible to take the Principles and Practice of Engineering exam.

Passing the Principles and Practice of Engineering exam is a vital step in one's engineering career. It is a major milestone that signifies a high level of expertise in the engineering field. Through the completion of this project our team gained valuable experience in the field of engineering that will be beneficial in our careers.

Authorship

This report consists of the work from Luca Cerasani, Sam Malafronte, and Connor Sakowich. All of the group members contributed equally to the report and the presentation. The following authorship shows the primary author for each section. All parts were edited by the whole project team.

Section	Author
Abstract	All
Acknowledgements	All
Capstone Design Statement	All
Professional Licensure	All
1.0 Introduction	All
2.0 Background	All
2.1 Woodlands Village Condominium Complex	LC
2.1.1 Road Network Challenges	CS
2.2 Rutland, MA	CS
2.2.1 Road Network Challenges	SM
2.3 Pavement Management	SM
2.3.1 Pavement Management Systems	CS
2.3.1.1 Pavement Management Softwares	LC
2.3.1.2 Data Collection Methods	CS
2.3.1.3 Reporting of Data	SM, LC
2.4 Road Design	SM
3.0 Methods	All
3.1 Understand and analyze current pavement management softwares.	CS, SM
3.2 Investigate road deterioration and how road distresses can lead to failures.	LC
3.3 Collect and analyze data on the current conditions of roadways in Woodlands Condominium Complex and Rutland, MA using a pavement management system.	All
3.4 Develop a cost estimate for road resurfacing for Woodlands Condominium Complex.	LC
3.5 Develop a technical memorandum encompassing a long term plan for both woodlands Condominium Complex and Rutland, MA.	CS, SM
3.6 Present a pavement management plan to each sponsor.	All
4.0 Results	All

4.1 Identify the pavement management software which will best serve the two sponsors.	SM
4.2 Through research and analysis of road distresses the team created a road distress table.	LC
4.3 Develop a technical memorandum to present to Woodlands condominium complex.	CS
4.4 Develop a technical memorandum for Rutland, MA.	All
Conclusion	CS
Appendices	All

Table of Contents

List of Figures and Tables

1.0 Introduction

In the foreseeable future, traffic is not going to decrease, oil prices are going to rise, and major weather events increasing road deterioration are becoming the norm. The need to have a system in place to maintain and repair road networks is at a premium. A pavement management system is an essential tool for towns and communities to easily manage their road networks and help make road repair decisions.

The Pavement Management MQP analyzed road conditions using a pavement management system in the Town of Rutland, Massachusetts and the Woodlands Condominium complex in Lunenburg, Massachusetts. Using the data provided by the software, the team recommended options for each sponsor to improve their respective road network.

Woodlands Condominium complex is a 47-unit development established in 1993. The roads were constructed between 1993 and 2001. The traffic volume mainly consists of the members that live in the condominium complex. The heaviest traffic loads are the weekly trash trucks and the snow plows during the winter. The road network is in relatively good condition. Currently, the road network has some visible distresses but as the age of the roads continues to increase year after year, a plan is needed for the management of the complex's roads (B. Pease, personal communication, September 13, 2018).

Rutland is a small town in Central Massachusetts with a population of about 9,000 residents (Town of Rutland). The town maintains 100 miles of roadways, including seven to ten miles of unpaved gravel roadways. There are two main roads which run through the middle of the town, Route 56 and Route 122A. These two roads have the highest traffic volume and withstand the largest traffic loading in the town. The town's Department of Public Works (DPW) maintains and repairs Route 56 and all the other roadways in the town using the yearly Chapter 90 funds, while Route 122A is maintained by the Massachusetts Department of Transportation. Most of the roadway repairs in the town are subcontracted out due to the insufficient staffing and equipment at the DPW (G. Kellaher, personal communication, September 17, 2018).

The common problems faced by both the Woodlands Condominium complex and the Town of Rutland is that they both suffer from a lack of financial funding and a pavement management plan. The condominium complex recently installed a yearly plan to allot $52,000 a year into their reserve fund. This reserve fund's primary use is for long-term maintenance and major road and wastewater repairs (B. Pease, personal communication, September 13, 2018). For the Town of Rutland, a large portion of the budget goes to the regional school system and the town receives most of its road maintenance money from Chapter 90 Program. Using the Chapter 90 Program, under the direction of Gary Kellaher, the town performed full-depth road reclamation to about a mile of roadway each year (G. Kellaher, personal communication, September 17, 2018).

The second problem the two road systems face is the lack of a pavement management plan. The condominium complex currently has no long-term management plan for their road network. The Board of Trustees is worried about the future of their road network and needs a plan to help them mitigate the foreseeable costs (B. Pease, personal communication, September 13, 2018). The Town of Rutland's previous pavement management practice consisted of the former DPW director travelling the 100 miles of road in town. The former director made pavement repair decisions based on his observations and industry experiences. However, the town does not have a long-term plan or pavement management software that prioritizes road repairs and tracks conditions of their roadways (G. Kellaher, personal communication, September 17, 2018). As of December 2018, Mr. Kellaher had retired, and their pavement management methods are uncertain moving forward.

To address these problems the MQP team developed an understanding of current pavement management practices and softwares. Through research the team identified the most practical pavement management software to be utilized in both locations. The team assessed the current condition of roadways in both locations and identified distresses using field data sheets. The collected data was entered into a pavement management software. The software generated 15-year outlooks, implemented future repairs and overall road network conditions. This data was used to generate a long-term pavement management plan for the Woodlands Condominium Complex and supported the software recommendation provided to Rutland, Ma. With all the information collected and qualitative research the team proposed final recommendations to each of the sponsors.

2.0 Background

The Background section provides an overview of the Woodlands Village Condominium Complex in Lunenburg, Massachusetts and the Town of Rutland, Massachusetts. It then discusses the problems that each face with their road systems in regard to pavement management. Then this section talks about Pavement Management Systems, long term plans and road designs.

2.1 The Woodlands Village Condominium Complex

The Woodlands condominium complex is located in the town of Lunenburg in the Central part of Massachusetts. The condominium complex covers 74.4 acres and borders Hickory Hill lake, which is a small manmade lake only containing small boats. In the 1980's the original design for the Woodlands Village condominium complex included 75 units, however only 47 units were approved to be built. The complex includes five four-unit buildings, five duplexes, and 17 single-family dwellings (B. Pease, personal communication, September 13, 2018). Single-family units have exclusive use of their property and are responsible for all yard maintenance including their driveways. The complex is governed by a Board of Trustees that consist of appointed members of the community. The Trustees are advised by three committees; Social, Financial, and Facilities to resolve issues within the community (Bushell, et. Al, 2017).

2.1.1 Road Network Challenges

The Woodlands condominium complex has concerns about the current status of their 1.1 miles of paved roads, and the future of their pavement moving forward. Currently, the only road maintenance done to the road network is yearly crack sealing, contracted by an outside vendor. The contract often goes to the contractor with the lowest bid. Besides the yearly crack sealing and the occasional filling of potholes performed by a resident, the road system has not received any other maintenance since initially being paved in the year 1993. Iris Court is the newest road in the complex, it was constructed in the year 2000, when the houses along that road were built.

Stormwater drainage is another issue for the condominium complex. There are several spots in the road network where puddling is evident. These puddles are often feet from the stormwater drains. This shows that the slope of the roads from the centerline to the curbing is imprecise. Typically, a road is constructed with a 2% downward slope from the centerline to allow for proper drainage of stormwater (A. Kiel, personal communication, November 13, 2018). When the stormwater fails to reach these storm drains it often flows off the road and into the residents' front yards. This runoff travels from the streets down residents' driveways causing erosion to some of their properties. Figure 1 shows an example of Woodlands Villages stormwater management problems. (B. Pease, personal communication, September 13, 2018).

Figure 1- The image on the left is a catch basin located in Woodlands Village. Many storm drains are poorly located which results in stormwater runoff issues. The image to the right is a swale the complex put in to solve the erosion from the stormwater runoff.

2.2 Rutland, Ma

Rutland is a small town in Central Massachusetts with a population of about 9,000 residents. The town maintains 100 miles of roadways, including seven to ten miles of gravel and dirt roads. This rural town has several financial struggles. The Department of Public Works' (DPW) budget is very limited due to the town's financial status; therefore, all of the road repairs are paid for through the Massachusetts Chapter 90 Program (Town of Rutland).

2.2.1 Road Network Challenges

Rutland is currently having several issues with their roads. Their biggest issue is financial cost of roadway maintenance. With Rutland being part of a regional school system for all grades, the school budget uses 57% of the entire town's budget. Due to this, the town allocates no funds to road maintenance. This forces the Rutland DPW to find the funds elsewhere for road maintenance. The town currently receives around $375,000 a year through the Massachusetts Chapter 90 Program (Massachusetts Department of Transportation, 2018) (Figure 2). The DPW believes it is more beneficial to perform full-depth road reclamation of the roads rather than using a short-term fix, such as placing a top coat on a poorly constructed subbase. In 2017, the town performed full-depth road reclamation of about 1.5 miles of road, which cost Rutland $490,000 (G. Kellaher, personal communication, September 17, 2018). Due to the high cost of full-depth road reclamation, the DPW is only able to improve an average of 1 mile of roadway each year.

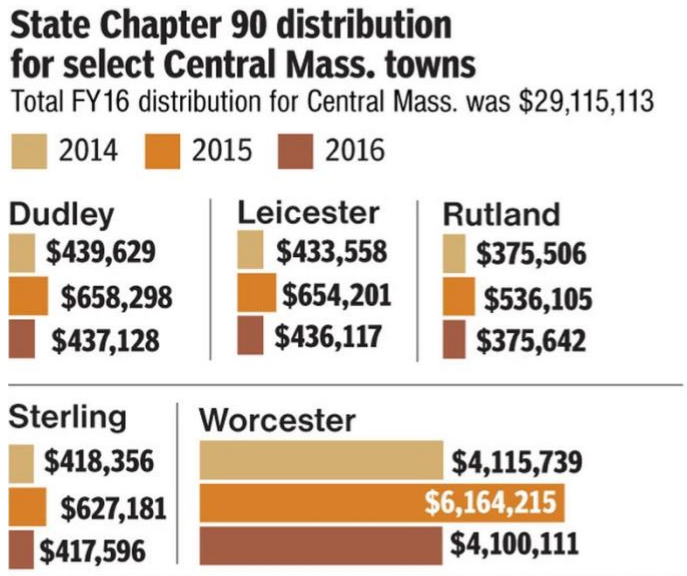

Figure 2- This image shows the funding for each town in central Massachusetts provided by the Chapter 90 Program in 2014, 2015 and 2016. Due to Rutland's limited budget, the towns road maintenance and repair is limited to their Chapter 90 funding. (Barnes, 2016)

There are two main roadways in Rutland, Route 122A and Route 56 which both receive high traffic volumes including a lot of heavy truck traffic. Route 122A is maintained by the Massachusetts Department of Transportation (MassDOT). Route 56 and all other public roadways in Rutland are maintained by the DPW. The maintenance and repair processes are done by a self-evaluation, using no pavement management system. Roads that look like they are in the worst condition are chosen for maintenance that year. Some distresses the town's former DPW director looks for are alligator cracking, longitudinal and transverse cracking, potholes, warping, and crumbling edges (G. Kellaher, personal communication, September 17, 2018).

Recently, the town of Rutland has been working to be eligible for funding through the Massachusetts Complete Streets Program. This 3-tier program was developed to help communities improve their roads for safe travel for all modes of transportation. In order for a town to complete the program they must:

1) Implement a Complete Streets Policy
2) Develop a Complete Streets Prioritization and Plan Development

3) Get Project Approval and Notice to Proceed.

Rutland is in tier 3, the final step of the Complete Streets application. At this point Rutland has developed a complete inventory of roads and projects which can improve the overall safety of their roads. While this is a great program, the funding is for towns to construct sidewalks on already existing roads, add separated bike lanes to roads, create pedestrian crosswalks and many other pedestrian, bike or bus safety improvements (Massachusetts Department of Transportation).

2.3 Pavement Management

Road networks are an important part of the transportation industry that millions of Americans use daily. In 2011, The American Association of State Highway and Transportation Officials estimated that roughly $2 trillion dollars was needed to repair and rebuild all the deteriorated roads, bridges and other infrastructure components in the nation. In 2017, the Federal Highway Administration said they needed $836 billion for improvements of federal roadways. The large investment that the nation has placed into the road networks creates a need to properly maintain and manage these roads (Frank, 2017). The idea of pavement management allows for municipalities and agencies to have an analyzed approach to managing a road network. This analyzed approach has been backed by the American Association of State Highway and Transportation Officials (AASHTO) since the early 1980’s. The idea of managing pavement allows for decisions to be made strategically and cost effectively to maximize the potential of each road and the road network (AASHTO, 2012).

2.3.1 Pavement Management Systems

A Pavement Management System (PMS) is a vital aid to decision-makers, allowing them to accurately rate roads, project the lifespan of a roadway, and to prioritize maintenance (Figure 3). A PMS allows for road network managers to understand and see how the decisions they make will impact the short- and long-term lifespan of a roadway. Roadways are major financial investments for federal, state, and local governments, as well as private owners. These roadways directly affect the community’s transportation and quality of life, making a PMS essential to these entities (Federal Highway Association, 2013).

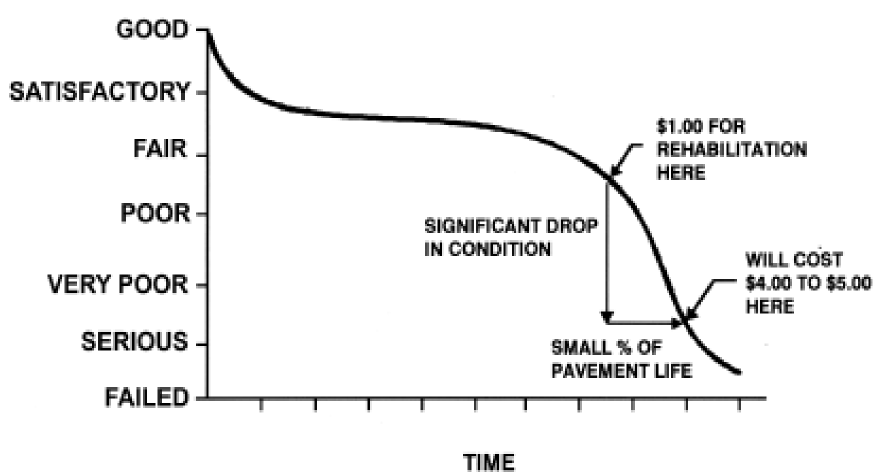

Figure 3- This graph shows the relationship between road condition and time. (Paver)

2.3.1.1 Pavement Management Softwares

Most pavement management softwares are similar, but they have some unique features which help the user understand the data and make it easier to make decisions. These softwares allow one to collect data, input it into the software to organize, and provide detailed results on the road network. All systems require a form of data collection, however early systems required the use of paper data tables for data management. Later developed were computer systems which made it easier to sort, analyze, and organize data. With the improvement of technology, pavement management softwares now have the ability to use Geographic Information Systems (GIS). Using GIS allows users to link data to specific roadways in the GIS map. Depending on the software, condition, construction data, traffic data and road history are all linkable. This feature allows for users to create a visual representation of the road network (Kulkarni & Miller, 2003).

A useful feature softwares have is the prediction models, which predict how long a road will last and how fast it will deteriorate (Figure 3). This analysis is based on the input field data, regression analysis, and/or mechanistic principles considering traffic load, pavement structure, and other factors. Once the analysis is done, programs will prioritize the roads, using weighted ranking systems of distresses, some programs use the weighted system developed by AASHTO. The prioritization gives users a list of top roads for rehabilitation. One important feature some softwares have to offer is an economic analysis. The analysis will compare the cost of different rehabilitation strategies and provide the most cost-effective method for improvement. Some softwares require the user to input costs for construction activities and other softwares use cost models that have been generated U.S. Highway Association (Kulkarni & Miller, 2003).

2.3.1.2 Data Collection Methods

Field surveys are the primary data collection method used for pavement management. However, there are a variety of ways that a field survey can be conducted. One of the easiest and most cost-efficient ways, is a visual survey, where an individual walks or travels the roadways and looks for distresses visually. When a distress is identified it is measured and recorded using a field data sheet or logged directly into a PMS software through the use of a mobile application.

Another method for data collection is the use of a vehicle attachment. There are several kinds of attachments that have varying functions. Some of the attachments use Ground Penetrating Radar (GPR) or other non-contact sensor systems which measure the thickness of the roadway and are useful to track the performance and wear of the road. Other vehicle attachments use contact sensor systems which look more so at the structural capacity and friction of the roadways (Pavement Resource Program at Rutgers University).

2.3.1.3 Reporting of Data

Dr. Nick Vitillo, of the New Jersey Department of Transportation stated, “A Pavement Management System is designed to provide objective information and useful data analysis so that road managers can make more consistent, cost-effective decisions related to the preservation of a pavement network”. This data analysis is done using the algorithms and pavement grading scale each individual software uses. Each software takes the collected field data and produces a pavement condition grade for each road. These grades vary by system, but generally include either a number scale or letter grade for roads. The software can then execute a forecast of future conditions for the road based on the deterioration curve. These graphs are coupled with spreadsheets that show the deterioration and estimated life span of the roadway (Pavement Resource Program at Rutgers University). The graphs and spreadsheets are extremely beneficial to roadway managers because it allows them to analyze timing options of roads, perform economic analysis of repairs, prioritize, and project future budgets (Ognejenovic, et. Al, 2016) (Vitillo).

2.4 Road Design

In the United States alone, there are over 2.7 million miles of paved roadways and 94% of those roads are paved with asphalt. While many people might not think about the complexity of the design of a roadway, an asphalt road is meticulously designed to withstand high amounts of stress and loads from the trucks and cars that drive on them. Flexible asphalt pavements are usually made up of layers and are placed in increasing quality, with the surface pavement being the highest quality. These layers are typically known from the bottom up as the subgrade, subbase, base, and binder and/or surface (Figure 4) (Mallick, R. & El-Korchi, T., 2013).

The thickness of each road layer is dependent upon the load it is going to withstand (Increased loading results in increased thickness, an airports runway is significantly thicker than a highway, which is significantly thicker than a rural road). Typically, the layers of the roads are made up of coarse aggregate and asphalt binder. The layers closest to the surface have a much higher asphalt binder content which results in a more expensive material. This higher asphalt binder content is needed on the surface and close to the surface to fortify the road to help it withstand the elements (snow, ice, rain) and the loads being directly applied from tires (Mallick & El-Korchi., 2013).

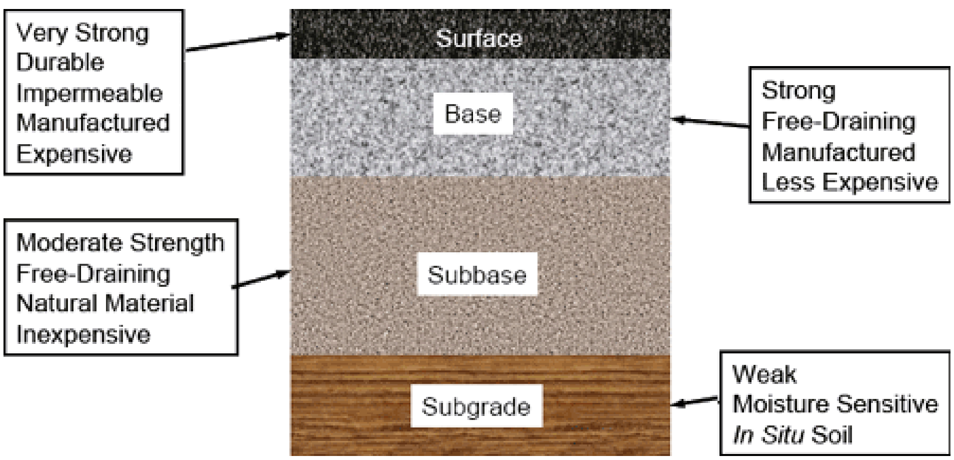

Figure 4- This image shows the layers of material of a typical roadway. (U.S. Department of Transportation)

Subgrade

The subgrade is the compacted ground beneath a road, and the thickness of this base layer is considered to be infinite. As the base of the road, the subgrade must be able to support loads which are passed from the pavement layers placed above. The ability to withstand loading without much deformation has to do with the type of soil, the degree of compaction, the stiffness of the soil and the moisture content (Khan, 2015).

Subbase

The sub base layer’s primary role is for structural support for the base and surface. The subbase is constructed out of higher quality material than the subgrade soils and many times consists of crushed aggregate or engineered fill. Along with structural support, having the ability to properly drain moisture out or the subbase is important to prevent frost heaves (Khan, 2015).

Base

The primary role of the base layer is to support the load capacity of the surface by adding stiffness, resistance to fatigue and thickness to the road to disperse the loading. The base layer is the layer right below the surface layer. The base usually consists of lower quality aggregate and a lower asphalt binder content than the surface (Yoder & Witczak, 1975).

Binder/ Surface

The binder and or surface layer is the most expensive layer in a road design, this cost is due to a higher asphalt binder content in the hot mix asphalt. The surface layer withstands the direct loads from the vehicles driving on it, withstands the direct exposure to weather, prevents surface water from reaching the base, subbase and subgrade, and provides a smooth surface for vehicles to travel over (Mallick & El-Korchi, 2013).

3.0 Methods

The goal of the Pavement Management MQP was to provide a recommendation for a pavement management plan for the Town of Rutland and the Woodlands Village Condominium Complex to cost-effectively maintain their roads. To achieve the overall goal of this project, our team:

1. Understood and analyzed current pavement management softwares.
2. Investigated road deterioration, and how road distresses can lead to failures.
3. Collected and analyzed data on the current conditions of the roadways in the Woodlands Condominium Complex and Rutland, Ma using a Pavement Management System.
4. Developed a cost estimate for road resurfacing for Woodlands Condominium Complex.
5. Developed a technical memorandum encompassing a long-term plan for both Woodlands Condominium Complex and Rutland, Ma.
6. Recommended an affordable pavement management system beneficial to each location.

3.1 Understood and analyzed current pavement management softwares.

The team researched several softwares currently used by municipalities and private companies. The team's research included reviewing pavement management software vendor websites and conducting semi-structured interviews with companies and industry professionals. The team conducted interviews with Adam W. Kiel, P.E. (Senior Traffic and Transportation Engineer with the City of Framingham, Ma), civil engineering professor Dr. Rajib Mallick, P.E. (has performed extensive research in the transportation and pavement industry) and Pat Cotton, P.E. (Civil Engineer for Weston and Sampson). The team looked into how each pavement management software differs and how they are unique in their own way. A matrix was used to analyze the pavement management softwares. There are many pavement management softwares on the market and all of them accomplish the same thing, with slightly different features.

The team analyzed five different programs:

1. Agile Assets
2. IWorq
3. PAVER
4. Street Saver
5. Transportation Asset Management System

After speaking to Mr. Kiel, Dr. Mallick, and Mr. Cotton and performing analysis of each of the softwares, the matrix was broken into four main themes that could easily be compared. The four themes the team found most important were cost, usability, collection methods and grading/ranking system.

Cost was chosen to be a main theme because both of the sponsors had brought it up many times as a limiting factor in many of the decisions they make. When the team looked at usability there were two main criteria looked for in each software. The first was the time it took to learn and use the software. The team looked for the most user-friendly software that allowed inexperienced users to learn it quickly. This was very important in the search because the sponsors have very limited experience using pavement management. The second criteria the team looked for was the ability to incorporate GIS files. This allows the user to create a visual representation of the roadway network and be able to update roadway systems instantly upon inspection. To make the project worthwhile and long lasting the team wanted to recommend a software that would allow for continued use regardless of experience.

Data collection methods was a topic the team chose to incorporate into the matrix because of the sponsors limited experience in using pavement management, along with the cost that is associated with more intricate collection methods. The team decided that having simplistic data collection methods would be ideal for the sponsors. The last criteria the team looked at for the matrix was the way each software graded the roads. Each software used a different algorithm to grade and prioritize roadways. The prioritization is based on the need for maintenance to the roadway. The team analyzed which software most accurately reflected the condition of the roadways.

3.2 Investigated road deterioration, and how road distresses can lead to failures.

The team first developed an understanding of road distresses by identifying the most prominent distresses found in roadways. The team did this through independent research using the *Rehabilitation Strategies for Highway Pavement,* a project sponsored by the American Association of State Highway and Transportation Officials (AASHTO), and the Central Massachusetts Metropolitan Planning Organization's *Regional Pavement Report Update for 2017*. Both of these resources provided the team with an understanding of how distresses are formed and how various distresses impact roadways. The team decided it would be best to create a distress table to easily look at. This distress table incorporated types of distresses, causes of distresses and visible examples of the distress. This table was used throughout the field surveys in order for the team to correctly identify distresses in the roadways.

3.3 Collected and analyzed data on the current conditions of the roadways in the Woodlands Condominium Complex and Rutland, MA using a Pavement Management System.

After the analysis in Objective 1 was completed, the team used the selected software PAVER to create a field data collection sheet for conducting field surveys. This field data sheet included: road length and width, number of lanes, levels of traffic volume, as well as prominent distresses identified in Objective 2, with their square footage or length and severity level.

Using the field data sheets and the distress table from Objective 2 the team then conducted visual surveys of the roads at the different locations identified by the sponsors. This included the five roads (Iris Court, Moccasin Flower Drive, Royal Fern Drive, Wintergreen Court, and Trillium Court) in the Woodlands Condominium Complex totaling 1.1 miles of road length, and two subdivisions in Rutland, MA totaling 2.56 miles (Brunelle Drive, Carlson's Way, Marjorie Lane, Winifred's Way, Richards Avenue, Tenrod Road, Valley View Circle, Settlers Lane, Colonial Drive, and Proprietors Place). To conduct these surveys the team visually inspected each roadway on foot, identified and measured the distresses found using a walking wheel tape, and noted them on the sheet (Appendix B). The data collected was then imported into the pavement management software. The software provided graphs, construction reports, projected road deterioration, total road network conditions and gave the team the ability to properly and accurately analyze the road networks.

3.4 Developed a cost estimate for road resurfacing for Woodlands Condominium Complex.

The team researched and analyzed several cost estimates from very similar projects on the Massachusetts Department of Transportation project bidding website. Using this data along with a sample cost estimate template from the Federal Highway Association the team created an estimated cost for labor and materials for a complete resurfacing (2 inches of cold-milling and then 2 inches of surface asphalt) of the Woodlands Condominium Complex (Appendix E- Attachment C). Using information collected in method 3.3, the team calculated the square footage of the road network. This information was used to calculate the total amount of asphalt required for the project based on current asphalt prices per ton. Using the data from the Massachusetts Department of Transportation and the Federal Highway Association the team estimated the total number of hours, equipment costs, labor rates, and milling costs required to complete the project. After the team completed the cost estimate for the entire road network, a second estimate was developed to repair a portion of the network. The team made this second estimate by dividing the total project cost by the total square footage and finding the cost per square foot. This information was then multiplied by the square footage of the portion of the network in most need of repair.

3.5 Developed a technical memorandum encompassing a long-term plan for both Woodlands Condominium Complex and Rutland, MA.

The team decided a technical memorandum would be the best method to convey the results to the project sponsors. The technical memorandum for Woodlands was broken down into sections; the introduction, road network analysis, the recommendation (long term plan) and the cost estimate. The introduction was used to introduce the problems the sponsor faced and summarized the content of the document. The following section used the data calculated by the pavement management software PAVER to provide a road network analysis. The analysis provided current conditions of the roadways and a 15-year outlook on the deterioration of the roadways. Next, the team presented the recommendations to the sponsor. Incorporated into the recommendation were the constraints the team and sponsors identified. These constraints include social, financial, and logistical implications that could impact the community. Additionally, the team incorporated a cross sectional road design of a roadway in the Woodlands Condominium Complex, this cross section is an example of a repair option if full-depth reclamation was needed. The cost estimate from method 3.4 was incorporated into the technical memorandum to show the sponsor how expensive each option would be to improve the road network.

For Rutland, the team broke the memo into three sections; the introduction, the software analysis and the road network analysis. The software analysis section explains how the decision to recommend PAVER was made. In this section, the team explains how usability and cost were the main criteria looked at. Next, the team analyzed all Rutland roads specified in methods section 3.3. The analysis provided current conditions of the roadways and a 15-year outlook on the deterioration of the roadways. Additionally, the team performed three Maintenance and Repair (M&R) planning scenarios. This feature allows the user to input a budget and a target PCI then the software will generate a repair plan for the selected roadways. The repair plan consists of three different types of M&R; preventative (above critical condition, examples: crack sealing, fog sealing, pothole filling. etc...), stopgap (below critical condition, examples: crack sealing, fog sealing, pothole filling, etc...), and major (failure condition, examples: new construction, mill and overlay, etc..). Preventative and stopgap M&R both use the same repair options, the difference between them is when they are performed. Any work performed to a road with a PCI below 55 is considered stopgap, and any work performed to a road with a PCI above 55 is considered preventative. The three scenarios performed were to maintain, slightly increase and drastically increase the condition of the road network. The main reason an analysis was performed was to display the capabilities of the pavement management software and how it could aid in pavement management decision making.

3.6 Presented a pavement management plan to each sponsor.

Based on the previous methods, the team identified the most beneficial pavement management plan for each of the sponsors; Woodlands Condominium Complex and the Town of Rutland, Ma. The team has identified that the sponsor’s needs vary, thus resulting in a recommendation tailored to each sponsor individually. The team presented these recommendations individually to each sponsor in a technical memorandum and a formal presentation.

4.0 Results

The goal of the Pavement Management MQP was to provide a recommendation of a pavement management plan for the Town of Rutland and the Woodlands Village Condominium Complex to cost-effectively maintain their roads. This chapter will focus on the components, materials and the final designs of the potential solutions selected. Each section will follow the step by step procedure outlined in the methodology chapter.

4.1 Identified the pavement management software which will best serve the two sponsors.

In accordance with methodology section 3.1, after analyzing the matrix developed (Appendix C) and speaking with industry professionals, PAVER (version 7.0.9) was selected as the pavement management software which best fit the sponsors' needs. This software was originally developed in the late 1970's by the US Army Corps of Engineers, and Colorado State University has since taken the responsibility of maintaining and updating the software.

Cost was a primary reason PAVER was chosen for this project. PAVER's one-time cost of $999 was an attractive option for the project because there are no annual fees, and the price was comparable or cheaper than other softwares analyzed.

Usability was a key component in selecting PAVER; it offers downloadable apps, live updating of pavement condition indexes (PCI), GIS capability, and is appropriate for all users regardless of technical background. Dr. Rajib Mallick of Worcester Polytechnic Institute's Civil Engineering department, explained in an interview that from his extensive experience, PAVER's usability was unmatched in the field. To input data into the software, road networks can be broken down into branches and each branch can be broken down into sections. This feature allows roadways to be cataloged and easily organized.

PAVER offers extensive information on each distress including pictures and descriptions for each severity level. This information helps users with little to no experience identify distresses and import inspections. The PCI is a grading system used by PAVER which is affected by each inspection of the roadways and the age of each roadway. PCI is on a number scale 0-100 and broken down into seven categories; "Good" 100-86, "Satisfactory" 85-71, "Fair" 70-56, "Poor" 55-41, "Very Poor" 40-26, "Serious" 25-11, and "Failure" 10-0. This simplistic grading system creates easy to read data reports. The software is compatible with GIS mapping, which allows for the user to create a visual representation of the road network and its respective PCI.

With all of the previously stated information taken into consideration, PAVER pavement management software was chosen to be used for the data analysis portion of this project.

4.2 Created a road distress table.

In accordance with methodology section 3.2, the project team created a road distress table (Appendix D). This table is a compilation of information regarding road distresses. The team identified nine major distresses that were incorporated into the table; potholes, alligator cracking, rutting, longitudinal cracking, transverse cracking, depression, raveling and weathering, corrugations and drainage infrastructure. This table provided the team with background knowledge of road distresses, their causes, and how to visibly identify them. This table was essential during the field survey portion of the project allowing the team to accurately survey the roads.

4.3 Developed a technical memorandum to present to Woodlands Condominium Complex.

The project team developed a technical memo to present the detailed results of the team's analysis and provide repair options for the road network (Appendix E). This memo includes a pavement condition index (PCI) of each individual roadway and the total road network. Accompanying this information, is a fifteen-year projection of the PCI based on the deterioration rate calculated by PAVER.

From this analysis, the project team developed two separate recommendations for the repair of the road network. The first option, option A, was to cold-mill and resurface 2" of asphalt on Royal Fern Drive and Moccasin Flower Drive in the year 2024. Moccasin Flower Drive currently has the lowest PCI of all the roads. In the year 2024, Moccasin Flower Drive will reach a PCI of 55 with no maintenance performed from now until then (Figure 5). PAVER considers this to be in "critical condition" and identified the road as the one in most need of repair. The team identified that it could be difficult to contract reasonably priced work for Moccasin Flower Drive alone due to the small length of roadway (1,437 feet, .27 miles). The team identified that Royal Fern Drive (2,851 feet, .54 miles) was the second most traveled roadway in the complex, so this road was included in the resurfacing as well.

The project team developed a secondary recommendation (Option B) in the case that Option A is not implemented. This recommendation is to cold-mill and resurface 2" of asphalt for the entire road network in the year 2031. By the year 2031, PAVER projects that only 54% of the road network will have a PCI in "Good" condition with no maintenance performed from now until then (Figure 5). Delaying repair past this point would cause the road network to deteriorate at an accelerated rate. However, the 12-year time span would allow the Woodlands Condominium Complex to save the required funds for the repair.

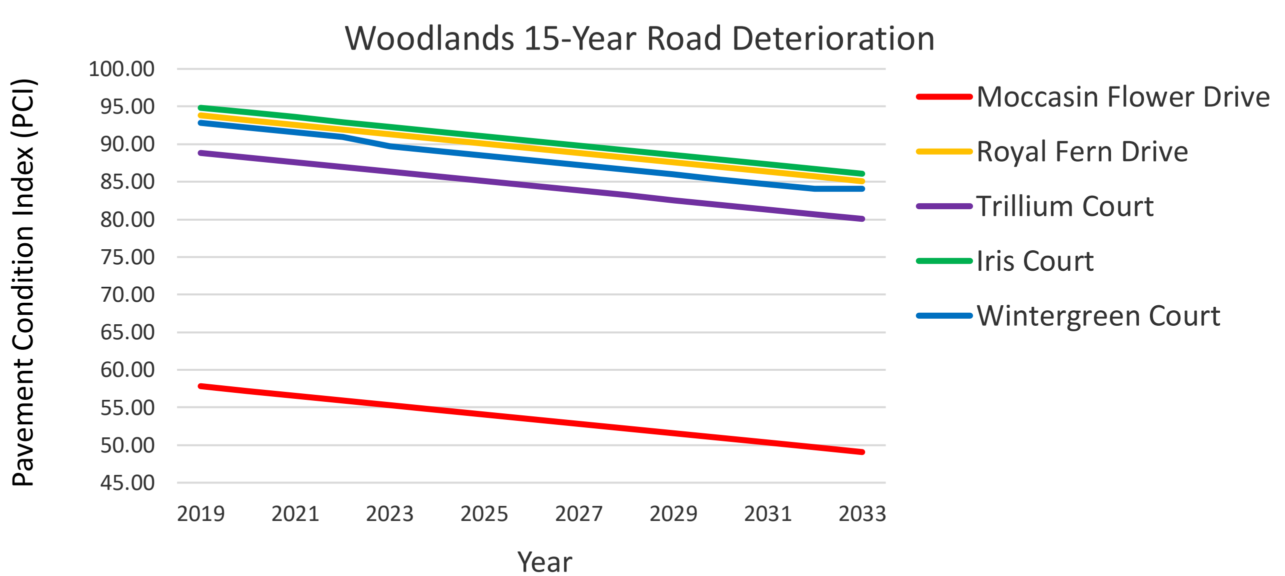

Figure 5- The graph displays the 15-year road deterioration for the roads in Woodlands Village.

The team then created a cost estimate for Option A and Option B. Considering materials, disposal, equipment, labor, and total project time, the team estimated a total value for each project. Option A was estimated about $197,000 for .81 total miles of roadway, while option B was estimated about $260,000 for 1.1 miles of roadway. The team's final recommendation was for Woodlands Condominium Complex to execute option A. This option was recommended because outside of Moccasin Flower Drive the remainder of the road network is in "Good" condition. Repairing the two primary access roads will increase the overall road network PCI and no major repairs will need to be done for the next 20 years.

Additionally, a cross-sectional design of Moccasin Flower Drive was provided in the memo. The team selected this road for the design because it had the lowest calculated PCI score in the network. The team believed it was necessary to provide a cross-sectional design for potential reconstruction if neither option A or B are executed. The cross-section is broken down into four layers; HMA Surface course (Surface/Binder), HMA Base course (Base), Dense grade crushed stone (Subbase), and Gravel base (Subgrade). Each layer's thickness is based on the needs for the complex and are specified in the design. Also, the road was designed with a 2% slope away from the median for proper drainage of stormwater.

4.4 Developed a technical memorandum for Rutland, Massachusetts.

The project team developed a technical memo to present the software recommendation and results of the analysis performed on the selected roads in Rutland (Appendix F). Using the matrix from methods section 3.1, and the result 4.1, the team recommended PAVER pavement management software for the town of Rutland to purchase and use moving forward. The decision to go with PAVER was impacted by two main criteria, cost and usability. Along with the software recommendation, the team provided a detailed analysis of the roads that were surveyed. In this analysis, the PCI's of each roadway were discussed, and graphs along with images were used to visually show the condition of the roads.

The team presented the results of the analysis performed on the roadways of two of Rutland's subdivisions. The first subdivision consisted of the roads; Brunelle Drive, Carlson's Way, Marjorie Lane, Winifred's Way, Richards Avenue and the second subdivision consisted of the roads; Tenrod Road, Valley View Circle, Settlers Lane, Colonial Drive, and Proprietors Place. After entering the field data into PAVER, the team ran a 15-year condition outlook on the roadways (Figure 6).

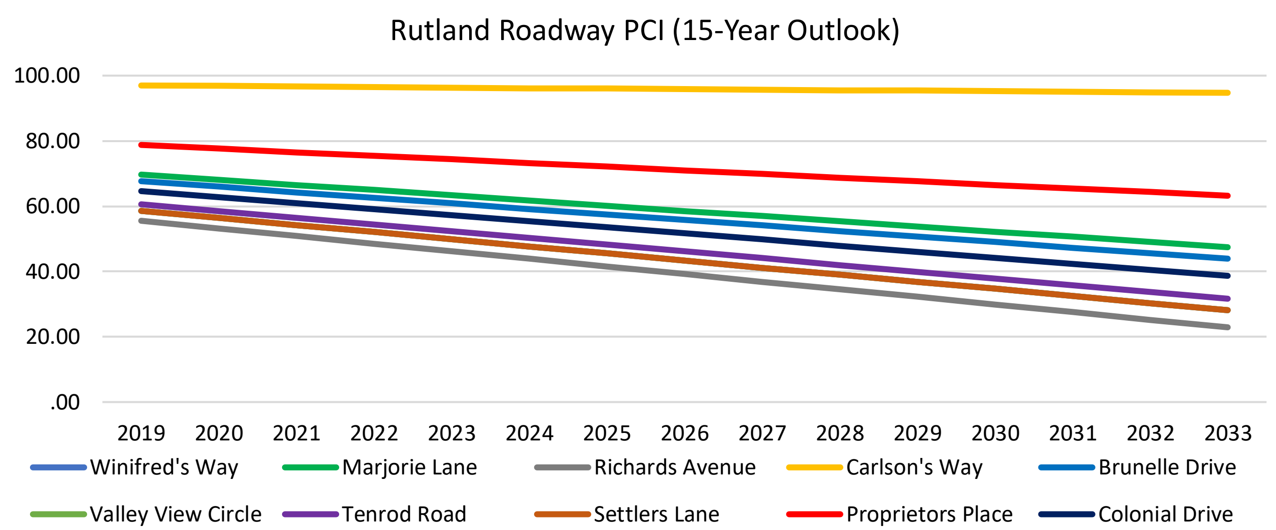

Figure 6- Surveyed Roadways in Rutland with a 15-year road deterioration projection. Winifred's Way, Valley View Circle and Settlers Lane have identical PCIs.

Of the 2.56 miles of roadway analyzed 92% of the road area was deemed to be in "Fair" condition, with a PCI between 56 and 70. Additionally, 3% of the road area was deemed to be in "Satisfactory" condition, with a PCI between 71 and 85. The final 5% of the road area was deemed to be in "Good" condition, with a PCI between 86 and 100. The current overall PCI of both subdivisions was calculated to be 65.42.

The team executed three maintenance and repair scenarios to display the capabilities of the feature. Table 1 displays the yearly spending for each scenario. Scenario 1, the team decided to execute a M&R plan with a goal to maintain the network PCI of 65.42 (+/- 3). PAVER suggested a work plan with a total cost of $285,000 to maintain the current PCI over the next 5 years (Appendix F- Attachment A). Scenario 2, the team executed a M&R plan with the goal PCI of 70 (+/- 3). This goal PCI was selected to place the roads in or near satisfactory condition. PAVER suggested a work plan with a total cost of $405,000 to achieve a PCI of 70 (+/- 3) over the next 5 years (Appendix F- Attachment B). Scenario 3, the team executed an M&R plan with the goal PCI of 85 (+/- 3). This goal PCI was selected to place the roads in or near good condition. PAVER suggested a work plan with a total cost of $775,000 to achieve a PCI of 85 (+/- 3) over the next 5 years (Appendix F- Attachment C). Included in the plans are year by year work summary for each roadway and also a yearly expenditure summary.

Table 1: Expenditure Summary for M&R Scenarios

Scenario	Total	2019	2020	2021	2022	2023
Scenario 1 (Maintain PCI)	$284,743	$51,486	$20,273	$88,910	$104,649	$19,422
Scenario 2 (Goal PCI 70)	$403,492	$51,486	$20,273	$88,910	$104,649	$138,172
Scenario 3 (Goal PCI 85)	$774,415	$51,486	$20,273	$251,694	$240,196	$210,763

This analysis was performed by the project team to display the ability for a pavement management software to catalog and manage road networks. More specifically, the team displayed the overall capabilities of PAVER and the benefits it presents to the sponsor.

Conclusion

The team's final recommendation to Woodlands Village is to consider the implementation of Option A. Option A consists of cold-milling and resurfacing 2" of asphalt on Moccasin Flower Drive and Royal Fern Drive. The team recommends implementing this option in the year 2024 and the estimated project cost was found to be about $197,000. The execution of this recommendation will cost-effectively improve the overall road network condition and increase the networks PCI a significant amount. The recommended repair will prolong the road network's lifespan and the team does not predict another major repair in the foreseeable future.

For the town of Rutland MA, the team's final recommendation is to consider investing in a pavement management software, specifically PAVER. The software's ability to categorize and prioritize roadways could be beneficial to the Department of Public Works. Using the software will allow the DPW to systematically manage their budget when making road network decisions.

If both sponsors consider the recommendations made, the team predicts they will see the long-term benefits of effectively managing their respective road networks. Road networks are large investments made by communities and municipalities to help improve the quality of life for its community members. These large investments should be properly managed. With budgets being the limiting factor in most road repair decisions, it has become evident to the project team that a pavement management system is vital for communities. If the system is used correctly, a community could save thousands of dollars maximizing investments made to the road network. This project has also opened the project team's eyes on how impactful a pavement management system could be to a community. In our careers, we hope to influence and help people see the necessity of having a pavement management system.

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Appendix A: Project Proposal

Pavement Management in Rutland, Massachusetts and at Woodlands Village

A Major Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree in Bachelor of Science
In
Civil Engineering

By:
Luca Cerasani
Sam Malafronte
Connor Sakowich

Date: 10/01/2018

Sponsoring Organizations:
Rutland Department of Public Works
Woodlands Village at Hickory Hills Lake

Project Advisors:
Professor Suzanne LePage, CEE

Capstone Design Statement

This project focuses on the pavement management systems of Rutland, Massachusetts and the Woodlands Village Condominium Complex in Lunenburg, Massachusetts. Currently Woodlands Village Condominium has no pavement management system and does road maintenance once a year with an outside subcontractor. The town of Rutland has a very basic form of pavement management, which consists of the Department of Public Works superintendent driving around and choosing roads that he feels need immediate repair. However, these two communities are worried for the future conditions of their roads and want to develop a plan to help improve and protect them for the future.

The team will analyze multiple pavement management systems to help find the right tool for our two unique sponsors. The two sponsors have very different road networks and needs; this may lead to them needing two different solutions to their problems. The team will use data collection methods designated by each pavement management software or design our own to help identify the best pavement management solutions. From the data the pavement management software outputs, the team will identify roads in need of total reconstruction. The recommendation will include a design solution for these roadways to best aid the community. The team plans to use AutoCAD, ArcGIS, and a traffic analysis software to help aid in the design of these roads.

During the project, design constraints will be factored in to the final recommendations for each community. The pavement management system will have to be affordable for the community, and reasonable for the number of staff and man hours each community has available. The system will be fitted specifically for each sponsor, so the system can be efficient as possible for each party. The roadway reconstruction will be sustainable for the community and cause very little harm to the environment. A pavement management system will improve road conditions in all environments making it easier and safer to travel on the roads daily, therefore, benefiting the community’s overall safety and quality of life. This project will aid these communities financially and improve their lifestyle for years to come.

1.0 Introduction

In the foreseeable future, traffic is not going to decrease, oil prices are going to rise, and major weather events are becoming the norm; the need to have a system in place to maintain and repair road networks is at a premium. A pavement management system is an essential tool for towns to easily manage their road networks and help make road repair decisions.

This Pavement Management Major Qualifying Project (MQP) is going to analyze the road conditions and pavement management systems available for the Town of Rutland, Massachusetts and the Woodlands Condominium complex in Lunenburg, Massachusetts.

Woodlands Condominium complex is a 47-unit development which was established in the 1990’s. The roadways in the complex are 20-30 years old. The traffic load only consists of the members that live in the condominium complex, and the complex does not receive passing through traffic because it has a closed gate at one end. The heaviest loads the complex’s road faces are the weekly trash trucks and the snow plows during the winter. The road network is in good condition currently with few visible structural problems but as the age of the roads continues to increase year after year, a plan is needed for the management of the complex’s roads (B. Pease, personal communication, September 13, 2018).

Rutland is a small town in Central Massachusetts comprised of 9,000 residents. The town maintains 100 miles roadways, including seven to ten miles of unpaved gravel roadways. There are two main roads which run through the middle of the town, Route 56 and Route 122A. These two roads receive the heaviest use and the largest loads in the town. The town’s Department of Public Works maintains and repairs Route 56 and all the other roadways in the town using the yearly Chapter 90 funds, while Route 122A is maintained by the state of Massachusetts. Most of the repairs in the town to the roadways are subcontracted out due to staffing at the DPW (G. Kellaher, personal communication, September 17, 2018).

The common problems faced by both the Woodlands Condominium complex and the Town of Rutland is that they both suffer from a lack of financial funding and a pavement management plan. The condominium complex recently installed a yearly plan to allot $52,000 a year into their reserve fund. This reserve fund’s primary use is for long term maintenance and repairs. With the complex’s limited budget, little to no funds are used for yearly care of the roadways (B. Pease, personal communication, September 13, 2018). For the Town of Rutland, a large portion of the budget goes to the regional school system and the town receives most of its road maintenance money from Chapter 90 funding. Using the Chapter 90 funding, the town is only able to repave slightly over a mile of road a year (G. Kellaher, personal communication, September 17, 2018).

The second problem these two-road systems face, is the lack of a pavement management system. The condominium complex currently has no management plan to rate the condition of the roads or a way to prioritize them in any way (B. Pease, personal communication, September 13, 2018). The Town of Rutland’s current management practice consists of the DPW superintendent travelling the 100 miles of road in town. The superintendent makes pavement repair decisions based on his observations and experience. However, the town does not have a long-term pavement management plan that prioritizes road repairs and tracks conditions of their roadways (G. Kellaher, personal communication, September 17, 2018).

To answer these problems the MQP team will develop an understanding of current pavement management practices. We will assess the current condition of roadways in both locations and identify damages. Next, we will place these damages into categories based on severity of damage and cost to repair. Following this, we will develop an understanding of how current roads are maintained and managed when they are deficient. Based on all of this research we will identify a pavement management system that effectively prioritizes roads, damages, and cost for both locations to use in future operations.

2.0 Background

The Background section provides an overview of the Woodlands Village Condominium association in Lunenburg, Massachusetts and the town of Rutland, Massachusetts. It then discusses the problems that each face with their road systems in regard to pavement management. Then this section talks about general pavement management practices.

2.1 The Woodlands Village Condominium Complex

The Woodlands Village condominium complex is located in the town of Lunenburg, Massachusetts in the Central part of the state. The condominium complex covers 74.4 acres and boards Hickory Hill lakes, which is a small manmade lake only containing small boats. In the 1980's original design for the Woodlands Village condominium complex it included 100 units, however only 47 units were approved to be built. The complex includes four four-unit buildings, five duplexes, and 25 single-family dwellings (B. Pease, personal communication, September 13, 2018). Residents here own their property and have the ability to do what they want or need to their house and or property. The complex is run by several committees that help make decisions on issues that arise within the community. All the committee's members are residents in the condominium complex, the committees are Waterfront, Social, Finance, and Facilities (Bushell, et. Al, 2017).

2.1.1 Governance

The residents living in the Woodlands Condominium complex own the title to their unit, but maintenance to the roads, lawns and land is taken care of by the association as a whole. The condominium complex has a Board of Trustees which acts as the government for the complex. The board makes all financial decisions and recently enacted a yearly savings plan which puts $52,000 a year in the complex's reserves. This money is reserved for large financial burdens that the complex may face in the future (B. Pease, personal communication, September 13, 2018).

2.1.2 Road Network Challenges

The Woodlands Condominium complex has concerns about the current status of their 1.1 miles of paved roads, and the future of their pavement moving forward. Currently the complex's main solution for any cracks in their pavement is yearly crack sealing. The contract often goes to the contractor who comes in with the lowest bid. Besides the yearly crack sealing and filling of potholes, the road system has not received any other maintenance since initially being paved in the late 80's. Primrose Drive is the most recent road to be completed in the complex and received its top layer of pavement in the early 2000's when the houses along that road where completed.

Figure 1- The image on the left is a catch basin located in Woodlands Village. Many storm drains are poorly located which results in stormwater runoff issues. The image to the right is a swale the complex put in to solve the erosion from the stormwater runoff.

Stormwater drainage is another issue for the condominium complex. There are spots on the road where puddling is evident. These puddles are often feet from the stormwater drains. This shows that the elevation of the roads in relation to the storm drains is not ideal, or that the storm drain itself was not initially set properly. When the stormwater fails to reach these storm drains it often flows off the road and into the residents' front yards. This runoff travels from the streets down residents' driveways causing erosion to some of the property. Figure 1 shows an example of Woodlands Villages stormwater management problems. (B. Pease, personal communication, September 13, 2018).

2.2 Rutland, Massachusetts

Rutland is a small town in Central Massachusetts comprised of 9,000 residents. The town maintains 100 miles of roadways, including seven to ten miles of gravel and dirt roads. This rural town has several financial struggles as do many small towns. The DPW's budget is very limited due to the town's financial status, therefore all of the road repairs are paid for through the Massachusetts Chapter 90 Program (Town of Rutland).

2.2.1 Governance

Rutland is governed by a five-member board of selectmen, a town administrator and an open meeting form of government. They are elected officials whose responsibilities entail the general operations of the town government. They develop their local policy based on the resident's direction at town meetings alongside the department heads regarding the issue at hand. Within the scope of our project, our sponsor deals with the planning board and the townspeople when it comes to the maintenance and management of their roadway systems. The planning board is responsible for community planning, reviewing, and making recommendations on all development proposals (Town of Rutland: Planning Board).

2.2.2 Road Network Challenges

Rutland is currently having several issues with their roads. Their biggest issue is financial cost. With Rutland being part of a regional school system for all grades, the school budget takes up 57% of the entire town's budget. Due to this, the town allocates no funds to road maintenance. This forces the Rutland Department of Public Works (DPW) to find the funds elsewhere for road maintenance. The town currently receives around $375,000 a year through the Massachusetts Chapter 90 program (Massachusetts Department of Transportation, 2018). Figure 2 shows the recent funding from Chapter 90 funding that Rutland and surrounding towns have received. The DPW believes it is more beneficial to regrade and resurface the roads for the long term rather than using a short-term fix, such as just placing a top coat on a poorly constructed subbase. In 2017, the town regraded and resurfaced about 1.5 miles of road which cost Rutland $490,000 (G. Kellaher, personal communication, September 17, 2018). Due to the high cost of regrading and resurfacing roadways the DPW is only able to complete about 1 mile of roadway a year.

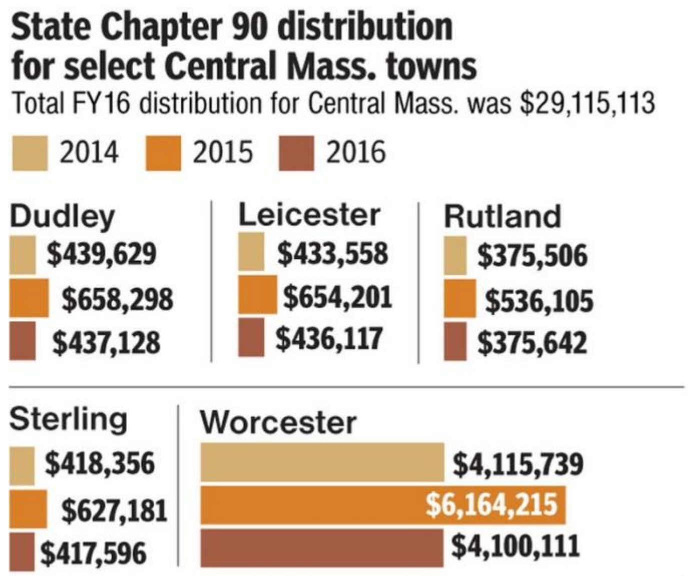

Figure 2- This image shows the funding for each town in central Massachusetts provided by the Chapter 90 Program in 2014, 2015 and 2016. Due to Rutland's limited budget, the towns road maintenance and repair is limited to their Chapter 90 funding. (Barnes, 2016)

Rutland subcontracts their engineering work and recently received GIS files of their utilities, however, the program does not currently track the road network and condition of the roads. There are two main roadways in Rutland, Route 122A and Route 56 which both receive high traffic volumes including a lot of heavy truck traffic. Route 122A is primarily maintained by the Massachusetts Department of Transportation, while Route 56 is maintained by Rutland's DPW. All other public roadways in Rutland are maintained by the DPW. The maintenance and repair process are done by a self- evaluation, using no pavement management system. Roads that look like they are in the worst condition are chosen for maintenance that year. Some indicators that the town DPW looks for in choosing to repair a road are alligator cracking, longitudinal and transverse cracking, potholes, warping, and crumbling edges (G. Kellaher, personal communication, September 17, 2018).

Recently, the town of Rutland has been working to be eligible for funding for Massachusetts Complete Streets Program. This program was developed to help communities improve their roads for safe travel for all modes of transportation. Rutland is in tier 3 of the Complete Streets application, at this point Rutland has developed a complete inventory of roads and projects which can improve the overall safety of roads. While this is a great program, the funding is for towns to construct sidewalks on already existing roads, add separated bike lanes to roads, create pedestrian crosswalks and many other pedestrian, bike or bus safety improvements (Massachusetts Department of Transportation).

2.3 Pavement Management Systems

A Pavement Management System (PMS) is a useful and impactful tool which can help decision-makers prioritize road maintenance and repairs. A pavement management system can impact investing into road networks and creates a thought-out plan for decision makers to understand the impacts of long- and short-term decisions as shown in the Figure 3 below being proactive in road maintenance by using a pavement management system will reduce the cost and increase the lifetime of the road (CMRPC. Pavement Management). The need for a quality management system of the roadways is greater today than it ever has been before, with traffic numbers continuously increasing, and without a projected major increase in roadway maintenance funds it is imperative to have a system in place to properly maintain and manage pavement (Federal Highway Association).

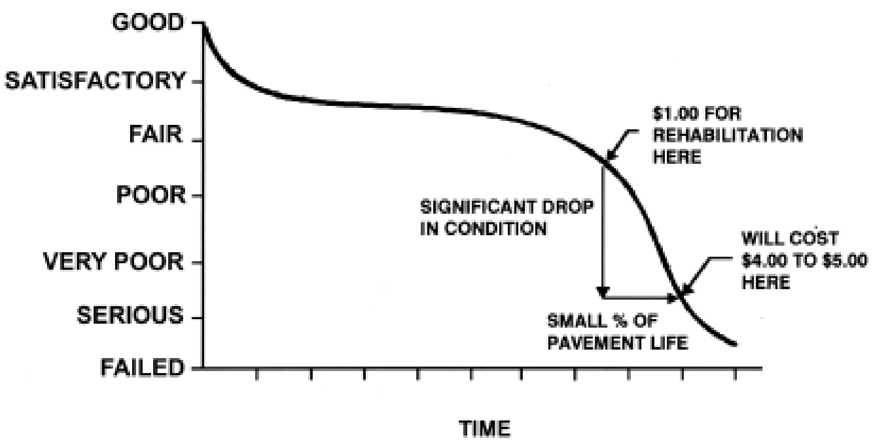

Figure 3- This graph shows the relationship between road condition and time. (Paver)

Roadways and road networks are huge financial investment for the state and the cities and towns within. These roads directly affect the community's transportation, and overall quality of life. Making the prioritization of roadways extremely important for the town to keep community members happy. Unfortunately, most if not all budgets are limited, making it difficult for municipalities to have continuous road maintenance, before making any decision it is crucial that they answer questions before committing to a project. Questions like:

What is the current condition of the roadway network?
Which roads should be repaired first?
What techniques should be used for best results?
What are the projected long-term consequences if we delay or defer repairs?

Answering questions similar to these prior to construction and maintenance will make it an easier decision and will help the whole road network improve (CMRPC. Pavement Management).

3.0 Methods

The goal of the Pavement Management MQP is to provide a recommendation for a pavement management system and develop a data collection system for the Town of Rutland and the Woodlands Village Condominium Complex to efficiently track and maintain their roads with cost in mind. To achieve the overall goal of this project, our team plans to:

1. Understand and analyze current Pavement Management Systems.
2. Investigate road deterioration, and how road distresses can lead to failures.
3. Collect and analyze data on the current conditions of the roadways using multiple Pavement Management Systems.
4. Assess each Pavement Management System
5. Recommend an affordable pavement management system beneficial to both locations.

3.1 Understand and analyze current Pavement Management Systems.

To understand current pavement management systems the team will research several systems currently used by municipalities or private companies. The teams research will primarily be looking at pavement management software vendors website as well as conducting semi structured interviews with companies we can contact. Additionally, the team is going to conduct interviews with entities using pavement management systems. The team will look into how each pavement management systems differ and how they are unique in their own way. A matrix will be used to analyze the pavement management systems, included in the matrix will be an initial cost, system maintenance cost, usability, weighted conditions, traffic analysis and any other things the team finds important.

3.2 Investigate road deterioration, and how road distresses can lead to failures.

Through preliminary research and information from objective one pavement management systems use certain distresses or criteria to rate the roads condition. These distresses are faults in the road that can result in damage and failure to the pavement. In order to truly understand how pavement management systems rates the condition of a road, the team must understand what the distress is. The team must understand road deterioration, what causes each distress, the type of damage it does to the roads, the safety implications caused by each, and the significance of each in terms of the integrity of the road. In order to do this, the team will conduct extensive research of each of these types of distresses or failures and create a chart defining what they are, what causes them, and the damage the distresses cause to the roadways.

3.3 Collect and analyze data on the current conditions of the roadways using multiple Pavement Management Systems.

Once a matrix is complete of all the analyzed pavement management systems the team will select the top tier of systems. The team will then collect current road condition data from a selected group of roads in each location by using the best collection method the pavement management system calls for. Using each pavement management system, the team will follow the procedure outlined by that system whether it be hand collection or electronically. The data will then be input into each pavement management system, and the graded results will be further analyzed. From this analysis the team will compare each pavement management system and how it graded the selected roadways.

3.4 Assess each Pavement Management System.

To complete this objective the team will create a cost benefit analysis of the pavement management systems. These costs will include the initial price, as well as, the lifetime maintenance of the system. The team will also analyze the data collection requirements of each system. The collection method must be feasible and affordable to our sponsor and their needs. The Woodlands Condominium Complex has 1.1 miles of roadways, so their needs differ from the town of Rutland's which has over 100 miles of roadways. In this step, we will weigh the options for each sponsor and identify which pavement management systems best fit their needs.

3.5 Recommend an affordable pavement management system beneficial to both locations.

From the data compiled from all previous objectives the team will recommend a pavement management system for each of our sponsors specifically. This system will be the most affordable and useful to each sponsor's needs. Additionally, the team will provide aid in initial setup of the system to include initial roadway data and how to effectively use the recommended pavement management system. The pavement management systems selected will identify roads that may need complete reconstruction. The team will use this information to design a complete reconstruction of a few selected roads and present them to the sponsors.

3.6 Projected schedule for project

Pavement Management MQP

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Project Start Date: 10/1/2018 (Monday)

Project Lead:

Display Week: 1

Week 1 (1 Oct 2018) · Week 2 (8 Oct 2018) · Week 3 (15 Oct 2018) · Week 4 (22 Oct 2018) · Week 5 (29 Oct 2018) · Week 6 (5 Nov 2018) · Week 7 (12 Nov 2018) · Week 8 (19 Nov 2018)

WBS	TASK	LEAD	START	END	Days	% DONE
1	**Objective 1**			-		
1.1	Research Pavement Management Vendors		Mon 10/01/18	Sun 10/21/18	21	0%
1.2	Interview entities using a PMS		Sun 10/07/18	Sun 10/21/18	15	0%
1.3	Create and input collected information into Matric		Mon 10/01/18	Sun 10/21/18	21	0%
1.4	Analyze the Matrix		Sun 10/21/18	Sun 10/21/18	1	0%
2	**Objective 2**			-		
2.1	Investigate Road Deterioration		Sun 10/21/18	Sat 10/27/18	7	0%
2.2	Develop Understand of Destresses		Sat 10/27/18	Fri 11/02/18	7	0%
2.3	Create a destresser definition chart		Sat 10/27/18	Fri 11/02/18	7	0%
3	**Objective 3**			-		
3.1	Select Top Tier PM Systems from Obj. 1 Data		Fri 11/02/18	Fri 11/09/18	8	0%
3.2	Select groups of roads to use as test roads for each PMS		Fri 11/02/18	Sun 11/04/18	3	0%
3.3	Collect current road condition data and input into each PMS		Fri 11/09/18	Sun 12/02/18	24	0%
3.4	Compare each PMS and graded roadways		Sun 12/02/18	Sat 12/15/18	14	0%
4	**Objective 4**			-		
4.1	Create cost benefit analysis of the PM Systems		Sat 1/05/19	Thu 1/17/19	13	0%
4.2	Analyze data collection methods for each system		Sat 1/05/19	Fri 1/11/19	7	0%
4.3	Weigh options for each sponsor		Thu 1/17/19	Tue 1/22/19	6	0%
5	**Objective 5**			-		
5.1	Recommend a PMS for each sponsor		Tue 1/22/19	Thu 1/24/19	3	
5.2	Provide aid in setup and effective use		Tue 1/22/19	Mon 2/04/19	14	
5.3	Create design plans for roads needing complete reconstruction		Tue 1/22/19	Fri 3/01/19	39	
6	**Breaks**			-		
6.1	October Break		Mon 10/08/18	Sun 10/14/18	7	
6.2	Thanksgiving		Wed 11/21/18	Sun 11/25/18	5	
6.3	Winter Break		Sat 12/15/18	Sat 1/05/19	22	

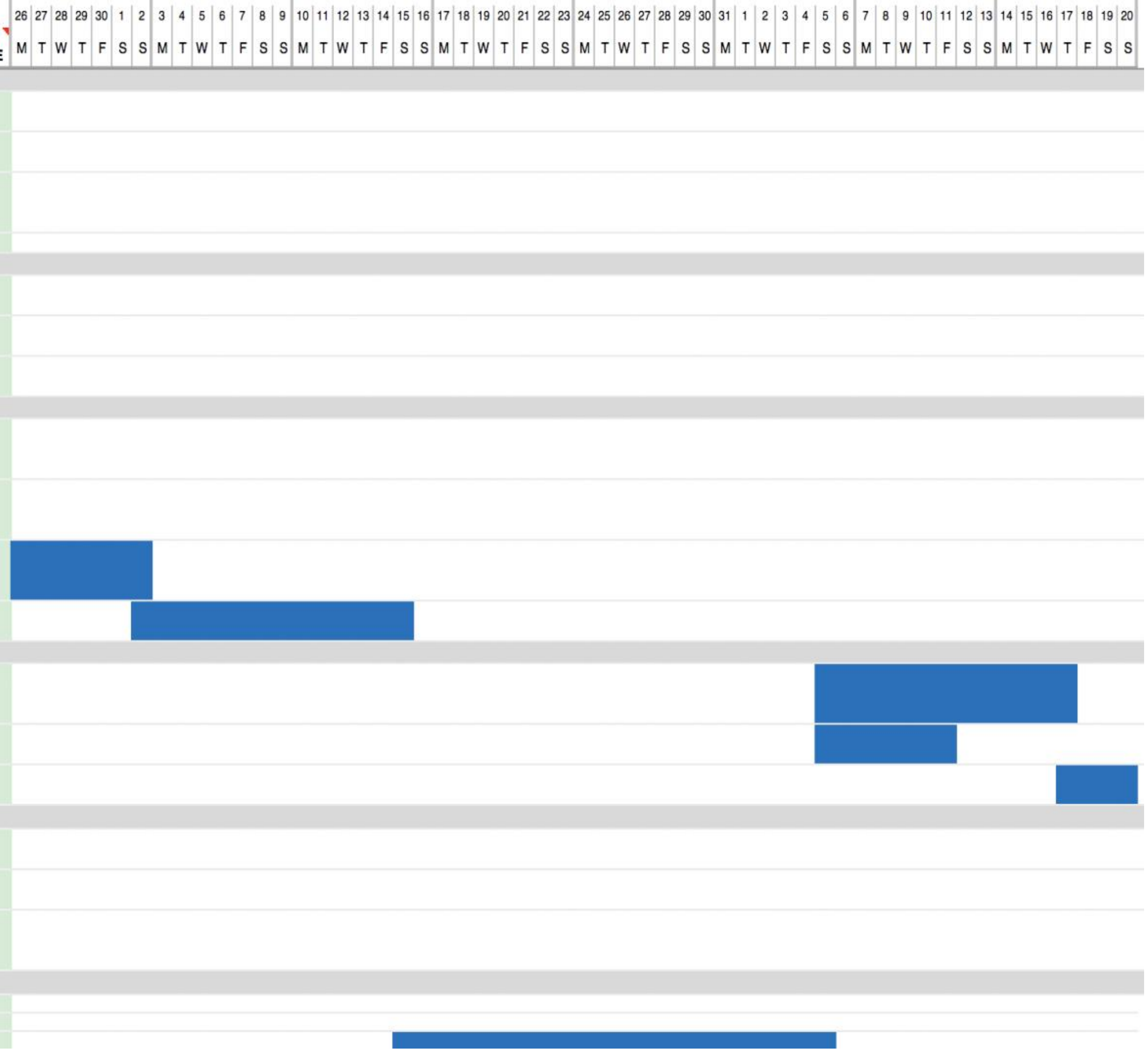
Pavement Management MQP

Gantt Chart Template © 2006-2018 by Vertex42.com.

Project Start Date: 10/1/2018 (Monday)
Project Lead:
Display Week: 9

Week 9 — 26 Nov 2018 | Week 10 — 3 Dec 2018 | Week 11 — 10 Dec 2018 | Week 12 — 17 Dec 2018 | Week 13 — 24 Dec 2018 | Week 14 — 31 Dec 2018 | Week 15 — 7 Jan 2019 | Week 16 — 14 Jan 2019

WBS	TASK	LEAD	START	END	Days	% DONE
1	**Objective 1**			-		
1.1	Research Pavement Management Vendors		Mon 10/01/18	Sun 10/21/18	21	0%
1.2	Interview entities using a PMS		Sun 10/07/18	Sun 10/21/18	15	0%
1.3	Create and input collected information into Matric		Mon 10/01/18	Sun 10/21/18	21	0%
1.4	Analyze the Matrix		Sun 10/21/18	Sun 10/21/18	1	0%
2	**Objective 2**			-		
2.1	Investigate Road Deterioration		Sun 10/21/18	Sat 10/27/18	7	0%
2.2	Develop Understand of Destresses		Sat 10/27/18	Fri 11/02/18	7	0%
2.3	Create a destresser definition chart		Sat 10/27/18	Fri 11/02/18	7	0%
3	**Objective 3**			-		
3.1	Select Top Tier PM Systems from Obj. 1 Data		Fri 11/02/18	Fri 11/09/18	8	0%
3.2	Select groups of roads to use as test roads for each PMS		Fri 11/02/18	Sun 11/04/18	3	0%
3.3	Collect current road condition data and input into each PMS		Fri 11/09/18	Sun 12/02/18	24	0%
3.4	Compare each PMS and graded roadways		Sun 12/02/18	Sat 12/15/18	14	0%
4	**Objective 4**			-		
4.1	Create cost benefit analysis of the PM Systems		Sat 1/05/19	Thu 1/17/19	13	0%
4.2	Analyze data collection methods for each system		Sat 1/05/19	Fri 1/11/19	7	0%
4.3	Weigh options for each sponsor		Thu 1/17/19	Tue 1/22/19	6	0%
5	**Objective 5**			-		
5.1	Recommend a PMS for each sponsor		Tue 1/22/19	Thu 1/24/19	3	
5.2	Provide aid in setup and effective use		Tue 1/22/19	Mon 2/04/19	14	
5.3	Create design plans for roads needing complete reconstruction		Tue 1/22/19	Fri 3/01/19	39	
6	**Breaks**			-		
6.1	October Break		Mon 10/08/18	Sun 10/14/18	7	
6.2	Thanksgiving		Wed 11/21/18	Sun 11/25/18	5	
6.3	Winter Break		Sat 12/15/18	Sat 1/05/19	22	



Pavement Management MQP

Gantt Chart Template © 2006-2018 by Vertex42.com.

Project Start Date: 10/1/2018 (Monday)
Project Lead:
Display Week: 15

WBS	TASK	LEAD	START	END	Days	% DONE
1	**Objective 1**			-		
1.1	Research Pavement Management Vendors		Mon 10/01/18	Sun 10/21/18	21	0%
1.2	Interview entities using a PMS		Sun 10/07/18	Sun 10/21/18	15	0%
1.3	Create and input collected information into Matric		Mon 10/01/18	Sun 10/21/18	21	0%
1.4	Analyze the Matrix		Sun 10/21/18	Sun 10/21/18	1	0%
2	**Objective 2**			-		
2.1	Investigate Road Deterioration		Sun 10/21/18	Sat 10/27/18	7	0%
2.2	Develop Understand of Destresses		Sat 10/27/18	Fri 11/02/18	7	0%
2.3	Create a destresser definition chart		Sat 10/27/18	Fri 11/02/18	7	0%
3	**Objective 3**			-		
3.1	Select Top Tier PM Systems from Obj. 1 Data		Fri 11/02/18	Fri 11/09/18	8	0%
3.2	Select groups of roads to use as test roads for each PMS		Fri 11/02/18	Sun 11/04/18	3	0%
3.3	Collect current road condition data and input into each PMS		Fri 11/09/18	Sun 12/02/18	24	0%
3.4	Compare each PMS and graded roadways		Sun 12/02/18	Sat 12/15/18	14	0%
4	**Objective 4**			-		
4.1	Create cost benefit analysis of the PM Systems		Sat 1/05/19	Thu 1/17/19	13	0%
4.2	Analyze data collection methods for each system		Sat 1/05/19	Fri 1/11/19	7	0%
4.3	Weigh options for each sponsor		Thu 1/17/19	Tue 1/22/19	6	0%
5	**Objective 5**			-		
5.1	Recommend a PMS for each sponsor		Tue 1/22/19	Thu 1/24/19	3	
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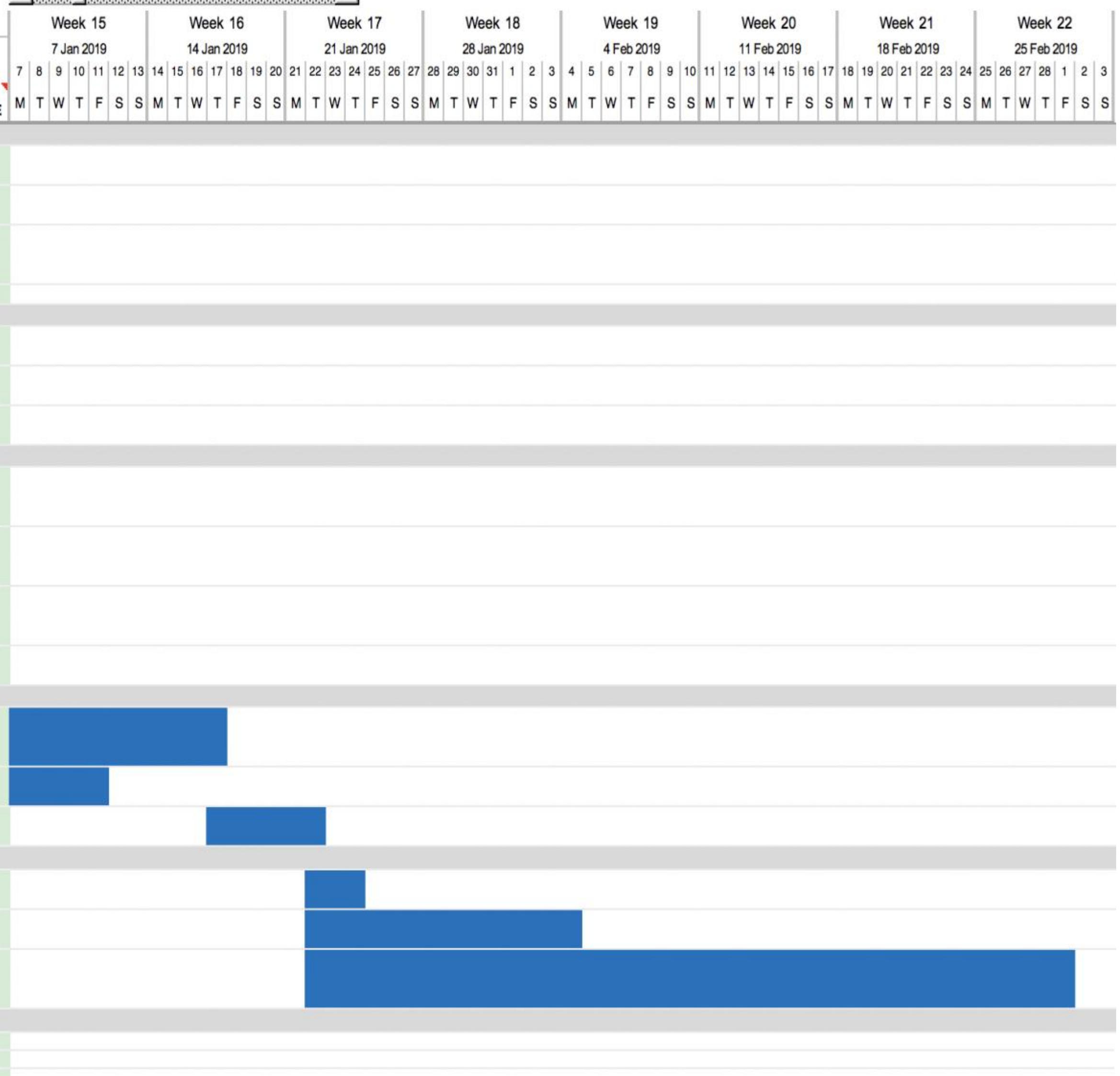
5.3	Create design plans for roads needing complete reconstruction		Tue 1/22/19	Fri 3/01/19	39	
6	**Breaks**			-		
6.1	October Break		Mon 10/08/18	Sun 10/14/18	7	
6.2	Thanksgiving		Wed 11/21/18	Sun 11/25/18	5	
6.3	Winter Break		Sat 12/15/18	Sat 1/05/19	22	



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Appendix B: Blank Field Data Sheet

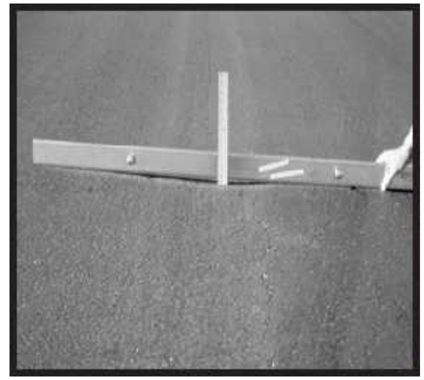
Pavement Management Field Data Sheet							
Road Section:		From:		To:		No.	
Road Length			**Shoulder Width**		**Traffic Volume**		
Road Width			**Curbing Y/N**		High	Med	Low
Sidewalk Y/N			**Catch Basins #**		**# of Lanes**		
	Distress Measure			Severity			Comments
	Length	Width	Depth	Low	Moderate	High	
Longitudinal Cracking							
Transverse Cracking							
Alligator Cracking							
Distortion							
Potholes							
Rutting							
Corrugations							
Drainage Infrastructure Comments:							

Appendix C: Pavement Management Software Matrix

	Cost				Collection Methods			GIS Compatability	Grading/Ranking System	Abilities	URL
	Initial Cost	Annual Cost	Online	User Interface	Initial Collection	Special Equipment	Annual updating				
Agile Assets-Pavement Analyst	$2000-$3000	The initial cost is an annual cost	No, used on an application	Downloadable Software, easily used on apps and shows graphically the roads.	Visual Survey, or having Agile Assets come to do the collection- this would result in it being very expensive	No	Manual updating	Yes	Three modes of rating roads, worst to first, prioritization based on need, or optimization based on need and cost	Preview Investment Outcomes, Optimize Work Plans, Improve Management Strategies, Produce Meaningful Reports	https://www.agileassets.com/products/pavement-analyst/
IWorq	$995/year	There is an annual subscription fee	Yes, It is entirely web-based, which means no installation, no upgrades, no setup or configuration, no software versions or releases, and no licenses. With iWorQ there is nothing to install, so all an agency needs is a password.	Uses GIS to graphically show the roads, looks to be rather easy to get the hang of using	Walking Visual Survey	No	Manual updating as new distressors appear	Yes	The website does not specifically talk about how roads are graded or ranked using this PMS but it can create a report regarding the condition of the pavement.	Custom Reporting, Data Management, Condition Assesment, Easy Budgeting	https://iworq.com/portfolios/pavement-management-software/
PAVER	$1000+~$1500 for training	There is no annual cost, but as new models of the software come out it would require updating resulting in increased costs	No, used on an application	Downloadable apps	Using Field inspector it is based upon visual collection, using image inspector a vehicle inspection is needed using GPS	Another method is to use a state of the art pavement image data collection method using a vehicle traveling at highway speed (Image Inspector).	The Pavement Condition Index (PCI) can be updated in real time as data is collected and input	Yes	Pavement Condition Index (PCI) based upon collection of pavement distresses data		http://www.paver.colostate.edu/FieldInspector.php
Street Saver	$1,500	annual initial cost for the software	no, downloadable software	Software, allows you to track inventory by allowing you to add street segments, also allows for maintenance tracking aswell.allows for bulk uploading, section spliting and combining. Also provides and interactive GIS map Showing all the road ways and shows selected roads information and history	Visual Survey	No	Manual updating	Yes	Provides condition reports for roads and asseses which ones are in most need of maitenence	Budget Scenarios, allowing you to place a budget in the program and it will produce th emost cost effective ways to invest given your specific budget. Project Selection, allows you to create aproject for a certain section of the road and can state wether its on time or delayed. Also keeps track of road inspections and treaments done to the roads. Program produces over 80 different reports including bidget anaylsis and financial summaries, also provides graphs to help viewer look at the data	https://www.streetsaver.com/home
Transportation Asset Management System (TAMS)	Free	0	no, downloadable software	Software, looks similar to the older verision of paver, allows you to add road segments and keep track of road maintenance done on the road, also provides a color coded map of the roads based on their service level scores.	Survey	No	Manual	Yes	Provides a remaining service level of each section of roads, Results show a service level score, money spent, and road treatments	Allows for street segments or signs for inventory, condition rating, analysis, and treatment tracking purposes	https://www.utahltap.org/software/tams.php

Appendix D: Road Distress Table

			Examples	
Road Distress	**Descriptions**	**Causes**	**Low Severity**	**High Severity**
Potholes	Typically, potholes occur in areas with a lot of alligator cracking and high-volume traffic. As alligator cracking becomes severe, pieces of pavement can become dislodged. This dislodged pavement is what is known as a pothole. These holes are usually small, generally less than 30 in. in diameter.	Alligator Cracking, High-Volume Traffic, Snow Plows		
Alligator Cracking	Cracks appear as interconnecting cracks in the wheel paths and grow into a large system of cracks. Cracking begins in the asphalt base where strain and tensile stress are the highest.	Weakly surface base or subgrade, heavy loading, poor drainage		

Rutting	A depression in the asphalt usually in the wheel path of the roadway. During precipitation rutting can be most noticed with puddling. After weather events rutting can have the greatest effect on travelers (ice in freezing conditions or hydroplaning).	Moving or collapse of material in sub base or base		
Longitudinal Cracking	There are two types of longitudinal cracking; wheel path and non wheel path. This form of cracking aligns parallel to the centerline of the road.	Non-Wheel Path: Cracks in stabilized base, poor compaction, poorly constructed paving lane joint Wheel Path: Heavy loading, high tire pressure		
Transverse Cracking	A form of cracking approximately perpendicular to the pavement centerline.	Poor pavement joints, weathering, sub base failure		

Depression	Surface areas of pavement with lower elevations than the surrounding pavement.	Frost Heaves, poor compaction during construction and utility placement		
Raveling and Weathering	Raveling is the dislodging of aggregate particles on the road surface. Weathering is the wearing away of asphalt binder from the surface.	The bond between asphalt and aggregate wears down and no longer holds together		
Corrugations	A series of closely spaced ridges and valleys.	Traffic loads and unstable liquid asphalt mix.		

Drainage Infrastructure	Proper drainage infrastructure is crucial for a road to maintain good condition and reduce the chance of failure. Standing water on a road can result in an increased chance for alligator cracking, transverse and longitudinal cracking and rutting.	Improper Installation of catch basins, manhole covers		

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Appendix E: Woodlands Village Technical Memorandum

TECHNICAL MEMORANDUM

To: Board of Trustees of Woodlands Condominium Complex

From: Luca Cerasani, Sam Malafronte and Connor Sakowich
Pavement Management MQP Team

Date: February 1, 2019

Subject: Road Network Analysis

Introduction

The Woodlands Condominium Complex contacted Worcester Polytechnic Institute with the need for a group of students to study and analyze the complex's roads, create a cost estimate for the resurfacing of the roads and provide a recommendation for a 10-year outlook. The roadways that have been analyzed by the project team were Moccasin Flower Drive, Royal Fern Drive, Iris Court, Trillium Court and Wintergreen Court in Lunenburg, Massachusetts.

The need for an analysis to be done came about because of the concern for the condominium complex to repave all 1.1 miles of the road network at one time and the financial burden that would come with it. Other constraints identified by the project's sponsors were the need for community approval and the impact of roadway resurfacing. A constraint which the project team identified was the concept of not being able to repave the road network in sections. The whole road network totals 1.1 miles of roadways and the project team believes a job less than .25 miles would result in large profit markups from the contractor.

Road Network Analysis

To conduct a road network analysis the project team first collected field data from roadways in the Woodlands Condominium Complex. This data collection was done by the project team walking the road network, recording key distresses, and measuring their respective dimensions using field data sheets. The recorded data was then entered into the pavement management software PAVER. PAVER then executed analysis on the road network as a whole, and each individual roadway. From the analysis the project team was able to determine that currently 70% of the roadways are in "Good" condition and 30% are in "Fair" condition (Figure 1). The 15-year outlook on the road network shows that four out of the five roads will remain in good condition over that 15-year time

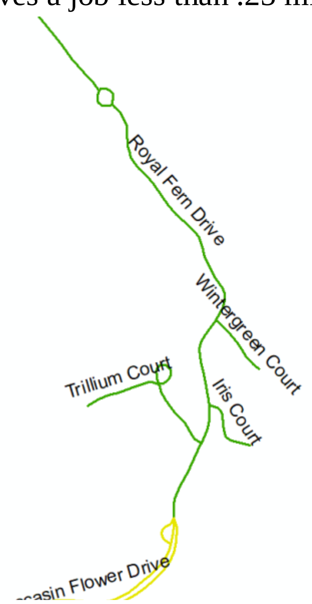


Figure 1: This is a color representation of each roadway's PCI in 2019. (Green=Good, Yellow=Fair)

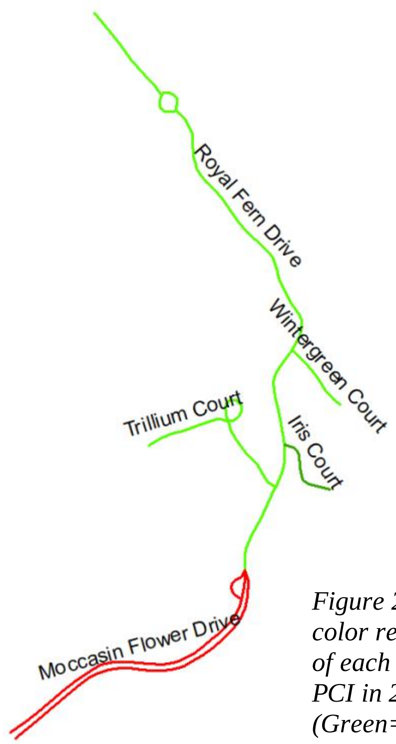


Figure 2: This is a color representation of each roadway's PCI in 2033. (Green=Good, Light Green=Satisfactory, Red=Poor)

span (Attachment A). Moccasin Flower Drive is the roadway with the lowest pavement condition index (PCI). According to PAVER's initial grade, Moccasin Flower Drive is approaching poor condition with a current PCI of 57.83. (A roadway with a PCI of 55 is considered to be in poor condition by PAVER).

The overall PCI of the road network is currently 82.49. Over the next fifteen years the road network will deteriorate to a PCI of 73.74. This number is primarily impacted by Moccasin Flower Drive and its condition has a large impact on the road network (Figure 2).

Recommendation (Long Term Plan)

After analyzing the data, the project team developed Option A. Option A is to cold mill and resurface 2” of asphalt on Royal Fern Drive and Moccasin Flower Drive in the year 2024. Through field surveys the team identified that the roads do not show signs of structural distresses. Additionally, none of the distresses were greater than 2” in depth and the team believes 2” of cold milling and resurfacing will resolve the distresses. The year 2024 was chosen because after that year Moccasin Flower Drive's PCI will be in “critical condition” (under a PCI of 55) according to PAVER. Allowing a road to stay in “critical condition” for a long period of time could result in the need for full depth reclamation of the roadway. The length of these two roads total .81 miles and are the primary roadways in the Woodlands Condominium Complex. The team identified that .81 miles was a suitable length for construction and would maximize the financial investment. A project of under .25 miles would result in a larger price per square foot due to equipment costs, labor costs and profit markup. Option A is a larger project and will cost approximately $196,800 but will have a greater financial benefit in the long term. After the recommended repair to the road surfaces the PCI of

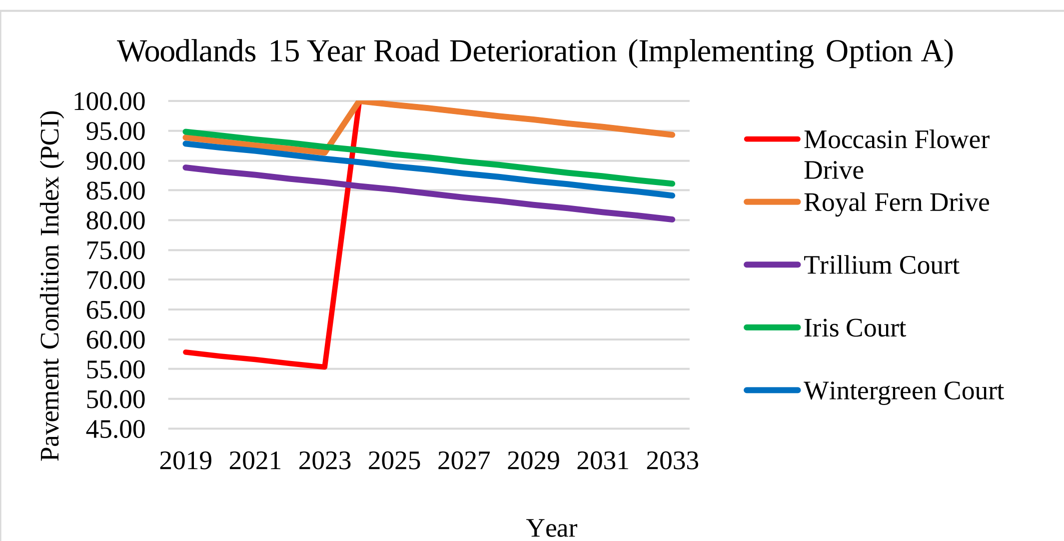


Figure 3: The graph displays the execution of the primary recommendation and how it effects the PCI of the repaired roads.

both Moccasin Flower Drive and Royal Fern Drive will return to 100.00 resulting in a higher network PCI (Figure 3).
Without the recommended repair to these roadways the overall network PCI is projected to be 73.74 in 2033. With the recommended repair in 2024 to these roadways, the Woodlands Condominium Complex can increase their overall network PCI to 91.85 in the year 2033 (Attachment B).

The team developed a second option, Option B. This option was developed if Option A is not executed by 2024. Option B is to cold mill and resurface 2” of asphalt for the entire road network in the year 2031. From now until then, the team advises to continue annual road maintenance. PAVER projects in the year 2031, only 54% of the road network will be in “Good” condition, 16% will be in “Satisfactory” condition, and 30% will be in “Poor” condition. The project team identified the year 2031 because delaying past this point will result in only 5% of the road network in “Good” condition. The year 2031 also provides the condominium complex with enough time to save for the large financial investment of $260,000.

These two options provide the Board of Trustees and community with two different courses of action to choose from moving forward.

An additional resource the project team created was a cross section of Moccasin Flower Drive to illustrate a road reconstruction. This resource may be helpful if total road reconstruction is absolutely necessary and can be used as a guideline to aid in construction. Based upon the data provided by PAVER, the project team does not anticipate total reconstruction (Gravel Base, Dense Graded Crushed Stone, Hot Mix Asphalt (HMA) Base Course, and HMA Surface Course) in the near future. This cross sectional was designed with a 2% slope from the median for proper drainage of stormwater to the catch basins. The cross-sectional design specifies the thickness and layer material needed for roadways in the Woodlands Condominium Complex based on the traffic volume they receive (Attachment D).

Cost Estimate (Attachment C)

The cost estimates were derived from the Massachusetts Department of Transportation and the Federal Highway Departments databases. The team was able to look at previous road estimates to help generate costs for each component such as operator costs, labor costs, and equipment costs. This cost estimate was calculated to accompany Option B. Option B was calculated first because the increased road length created a more accurate cost estimate. The team used the road’s length, width, and the 2-inch depth to calculate the total amount of asphalt needed for the project. That total amount was then used to calculate the total material cost for the project. The scope of the estimate includes the cold milling and disposal of the debris, resurfacing the road with 2 inches of asphalt, and site clean-up.

The asphalt required for this project was determined to be 1845 tons, costing $180,625. The duration of the project was determined to be 2 work days, and would cost approximately $8,000 in labor, $14,000 in equipment expenses and the cold milling would cost $57,000. The final cost of the entire project was estimated to be just under $260,000.

Based upon PAVER's analysis and given financial constraints, the team developed a second cost estimate derived from the previous estimate. The second cost estimate accompanies Option A. After estimating the entire road network, the team's second cost estimate is for the .81 miles of main road; Moccasin Flower Drive and Royal Fern Drive. The team calculated the cost per square foot to be $1.78. Using the square footage of Moccasin Flower Drive and Royal Fern Drive the calculated project estimate is $197,000.

The cost estimate which the project team produced was based on data from the year 2007 to 2018. Additionally, the project team made estimates on equipment, labor, and material cost based on research done throughout this project. All figures and estimates do not consider inflation rates.

Conclusion

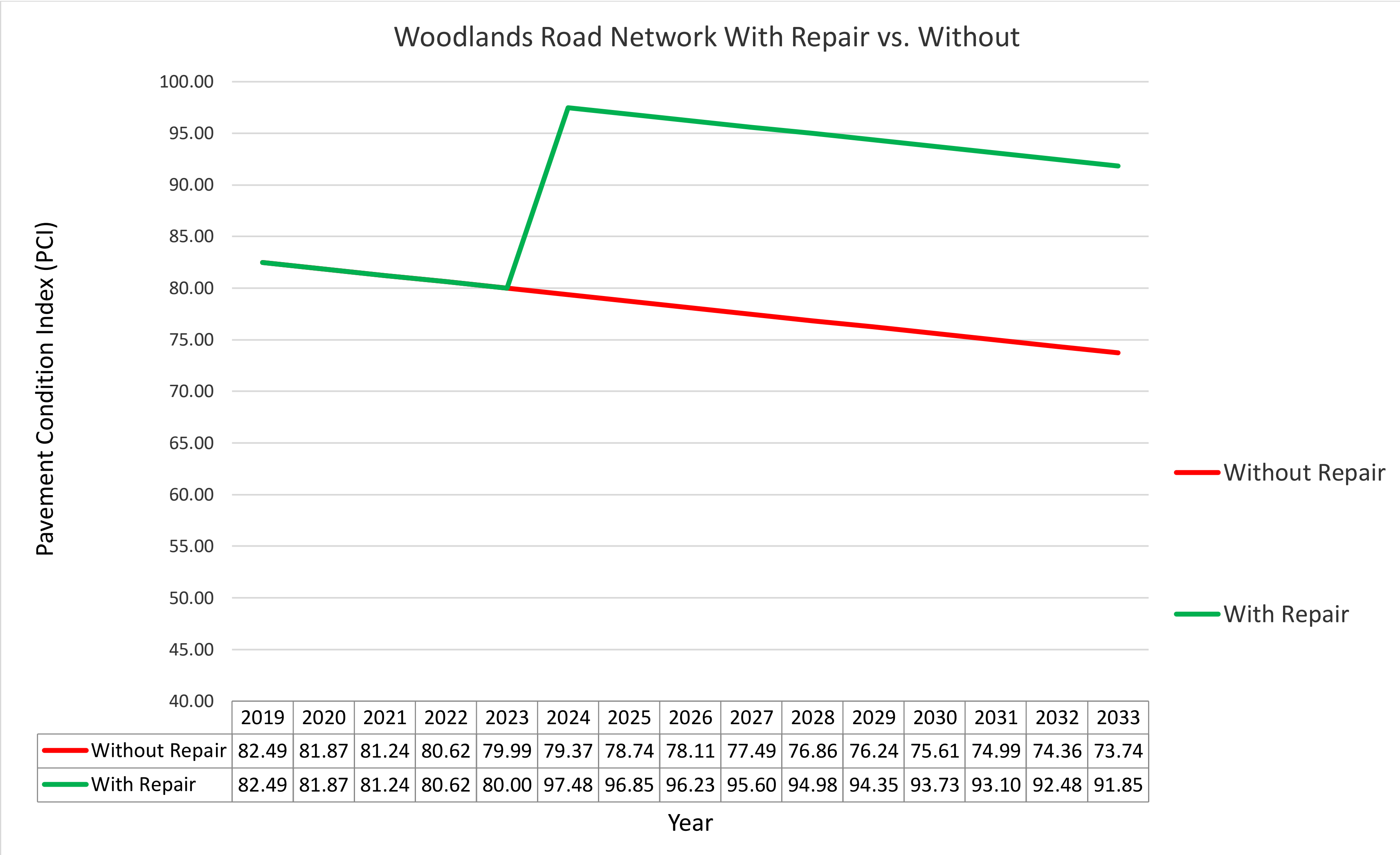
Moving forward, the team advises that the Board of Trustees of Woodlands Condominium Complex takes the recommendations made in this memorandum into consideration. Establishing a long-term plan for the road network will only improve the community and the quality of life of the residents. This memorandum will be accompanied by a full report that contains more detailed information regarding the project. The full report will be available at the conclusion of the project no later than March 10, 2019.

Pavement Management Major Qualifying Project Team
Worcester Polytechnic Institute
February 1, 2019

Attachment A: Woodlands 15-year Road Deterioration Graph

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Moccasin Flower Drive	57.83	57.20	56.58	55.95	55.33	54.70	54.07	53.45	52.82	52.20	51.57	50.95	50.32	49.70	49.07
Royal Fern Drive	93.83	93.20	92.58	91.95	91.33	90.70	90.07	89.45	88.82	88.20	87.57	86.95	86.32	85.70	85.07
Trillium Court	88.83	88.20	87.58	86.95	86.33	85.70	85.07	84.45	83.82	83.20	82.57	81.95	81.32	80.70	80.07
Iris Court	94.83	94.20	93.58	92.95	92.33	91.70	91.07	90.45	89.82	89.20	88.57	87.95	87.32	86.70	86.07
Wintergreen Court	92.83	92.20	91.58	90.95	89.70	89.07	88.45	87.82	87.20	86.57	85.95	85.32	84.70	84.07	84.07

Attachment B: Woodlands Road Network PCI Difference with Implementation of Option A.



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Without Repair	82.49	81.87	81.24	80.62	79.99	79.37	78.74	78.11	77.49	76.86	76.24	75.61	74.99	74.36	73.74
With Repair	82.49	81.87	81.24	80.62	80.00	97.48	96.85	96.23	95.60	94.98	94.35	93.73	93.10	92.48	91.85

Attachment C: Cost Estimate of Recommendations

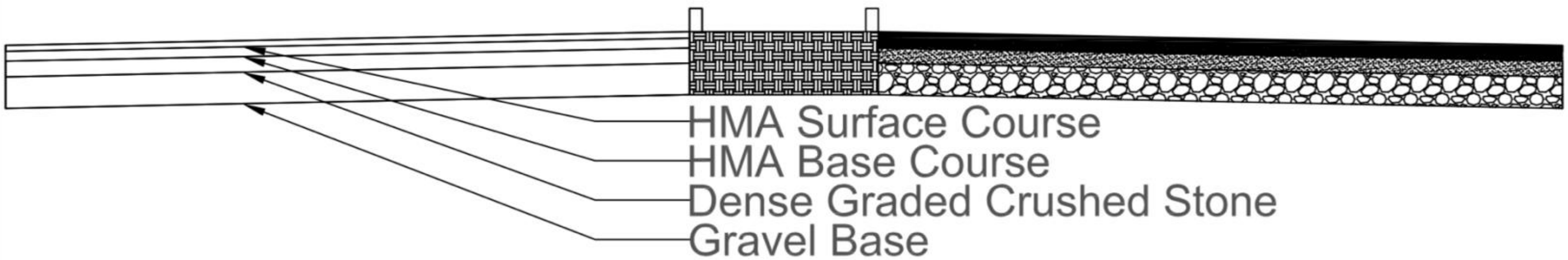
Cost Estimate Woodlands Condominium Complex						
Road	**Length (ft)**	**Width (ft)**	**Square Footage**	**Thickness (In)**	**Tons of Asphalt**	**Pavement Milling (.39/sq. ft)**
Mocassin Flower Drive	1437	29	41673	2	500	$16,252.47
Royal Fern Drive	3000	23	69000	2	890	$26,910.00
Wintergreen Court	315	23	7245	2	95	$2,825.55
Iris Court	524	24	12576	2	160	$4,904.64
Trillium Court	976	16	15616	2	200	$6,090.24
				Total:	1845	
				Price of Asphalt:	$180,625.50	
					Price of Milling:	$56,982.90

Equipment (Cost Per Hour)			
Description	**Quantity**	**Cost/Hour**	**Total Cost/ Hour**
Haul Truck (Owner/Operators)	8	$90.00	$720.00
Roller	2	$23.95	$47.90
Pneumatic Roller	1	$18.75	$18.75
Asphalt Paver	1	$78.05	$78.05
Bobcat Skidster	1	$23.95	$23.95
Total			$888.65

Total Hours	16
Total Equipment Cost	$14,218.40
Total Labor Cost	$7,986.08
Milling Cost	$56,982.90
Asphalt Material Cost	$180,625.50
Cost per Sqft	$1.78
Recomended length project cost (.81 Miles)	$196,798.79
Total length Project Cost (1.1 Miles)	$259,812.88

Labor (Cost Per Hour)			
Description	**Quantity**	**Cost/ Unit Hour**	**Total Cost/ Total Units Hour**
Foreman W/ Truck	1	$84.13	$84.13
Laborers	5	$31.51	$157.55
Equipment Operators	5	$51.49	$257.45
Total			$499.13

Attachment D: Cross Sectional Road Design of Moccasin Flower Drive



Layer	Thickness
HMA Surface Course	1.5"
HMA Base Course	2.5"
Dense Graded Crushed Stone	4"
Gravel Base	8"

Worcester Polytechnic Institute: Major Qualifying Project	Woodlands Condominium Complex Cross Sectional Road Design: Moccasin Flower Drive	Scale: $\frac{5}{16}$" = 1' Date: March 1st, 2019

Appendix F: Rutland, Massachusetts Technical Memorandum

TECHNICAL MEMORANDUM

To:	Joseph Buckley, DPW Director Town of Rutland, Massachusetts
From:	Luca Cerasani, Sam Malafronte, Connor Sakowich Pavement Management MQP Team
Date:	February 26, 2019
Subject:	Road Network Analysis and Software Recommendation

Introduction

The Town of Rutland, Massachusetts contacted Worcester Polytechnic Institute with the need for a group of students to study and catalog their road network. The town's network consists of about 100 miles of roadway, including seven to ten miles of unpaved gravel roadways. In the scope of the project, the team analyzed the pavement condition of 2.56 miles of roadway: Brunelle Drive, Carlson's Way, Marjorie Lane, Winifred's Way, Richards Avenue, Tenrod Road, Valley View Circle, Settlers Lane, Colonial Drive, and Proprietors Place.

The first problem the town faces is the lack of a true pavement management system. First, the team conducted analysis of pavement management softwares and identified PAVER as the best option. The team performed analysis of the road network using PAVER to demonstrate its capabilities.

The second problem the town faces is a limited budget due to funding. All road maintenance in the town is funded by the Chapter 90 Program yearly allocation of about $375,000. This limited budget allows for an average of 1 mile of full-depth road reclamation which was the previous method of repair.

The following software recommendation will be valuable to the Department of Public Works and aid future road network decision making. With such a limited budget, every investment is valuable. Using the software's data, the DPW director can systematically manage how the money is used, improving the road network of Rutland.

Software Analysis

The team has performed extensive research on several pavement management systems and through analysis the team has selected a software for the town of Rutland, Massachusetts. The software which the team is confident in recommending is PAVER (version 7.0.9). This software's primary responsibility is to track and maintain a database for a road network. It was initially created by the United States Army Corps of Engineers and has been further developed and maintained by Colorado State University. The two main reasons PAVER was chosen for the recommendation are cost and usability.

Rutland's former DPW director, Gary Kelleher, made it evident to the team that cost was a constraint due to a limited budget. For this reason, the project team made cost a significant criterion when analyzing the softwares. One thing which the team found appealing was the fact that PAVER requires a one-time fee of $999. Another software "IWorq", requires a $995 fee annually. In comparison, this makes PAVER very cost effective because the one-time purchase could provide a pavement management system for years into the future.

Another software which was looked at by the team was "Agile Assets", this software was the most expensive out of all the softwares the team analyzed. It required an annual fee of $2000-$3000 depending on which version was purchased. Along with the high annual costs, "Agile Assets" recommends they perform the field surveys. This would be a beneficial software if the town had the budget to pay for the annual costs and the work load of surveying the roads.

Rutland's DPW has never used a pavement management software. Therefore, usability was a major factor in choosing PAVER. The team looked to PAVER after speaking with Dr. Rajib Mallick, who is a professor in the Civil Engineering Department at WPI. In his experience, the PAVER software is simple enough for a first-time user to learn quickly but offers extensive features to analyze roadways. From the team's experience using PAVER, the software organizes the road network by breaking it down into "branches" and "sections." This allows the user to build a detailed inventory of the road network that can be navigated quickly. Another valuable feature offered by PAVER is a downloadable app for phones and tablets. The app allows users to create live inspections of roadways and update the pavement condition index in real time. While conducting an inspection, the software and app provide pictures and detailed explanations of each distress and severity levels. Regardless of technical background, the user can accurately update and record the condition of the roadway.

PAVER is capable of linking to GIS maps. This creates a visual representation of the road network and its condition. This is beneficial because the Massachusetts Department of Transportation already has GIS files of Rutland roadways. Using these files and the inventory included in them, Rutland would just have to inspect and update the roadways. PAVER can then produce reports and prioritize roads needing repair. In addition, PAVER allows the user to create work plans to identify which repair would be most beneficial, aiding the decision-making process.

Along with PAVER being easy to use and low in cost, the software also provides users with many forms of data analysis. The software creates projected road deterioration, can track and schedule maintenance and repairs, which allows the user to see the effects they have to the PCI of the roads. With all the capabilities within PAVER, the software can aid the director in making decisions regarding maintenance and budget.

Road Network Analysis

To conduct a road network analysis the project team first collected field data from roadways in Rutland, Massachusetts. This data collection was done by the project team surveying the roads, recording key distresses, and measuring their respective dimensions using field data sheets. The recorded data was then entered into the pavement management software PAVER. PAVER then executed analysis on the road network as a whole, and each individual roadway. The project team analyzed two subdivisions of roads. The first subdivision consisted of the roads; Brunelle Drive, Carlson's Way, Marjorie Lane, Winifreds Way, Richards Avenue and the second subdivision consisted of the roads; Tenrod Road, Valley View Circle, Settlers Lane, Colonial Drive, and Proprietors Place (Figure 1).

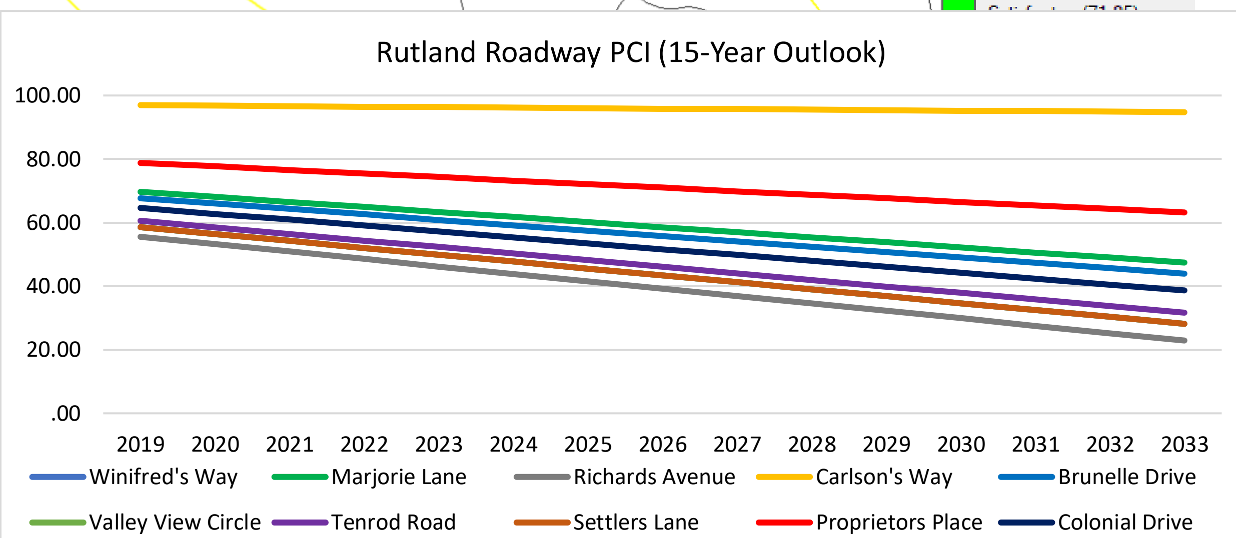


Figure 2: Surveyed Roadways in Rutland with a 15-year road deterioration projection. Winifred's Way, Valley View Circle and Settlers Lane have identical PCIs.

Of the 2.56 miles of roadway analyzed 92% of the road area was deemed to be in "Fair" condition, with a PCI between 56 and 70. Additionally, 3% of the road area was deemed to be in "Satisfactory" condition, with a PCI between 71 and 85. The final 5% of the road area was deemed to be in "Good" condition, with a PCI between 86 and 100 (Figure 1 and 2).

The project team entered the 2.56 miles of roadways as a road network and PAVER calculated the current PCI of all the roads surveyed to be 65.42. After performing a 15-year condition analysis, the overall score of the road network could drop to 40.04 in the year 2033, without any maintenance (Figure 2 and 3). This would place the two subdivision road networks in "Very Poor" condition.

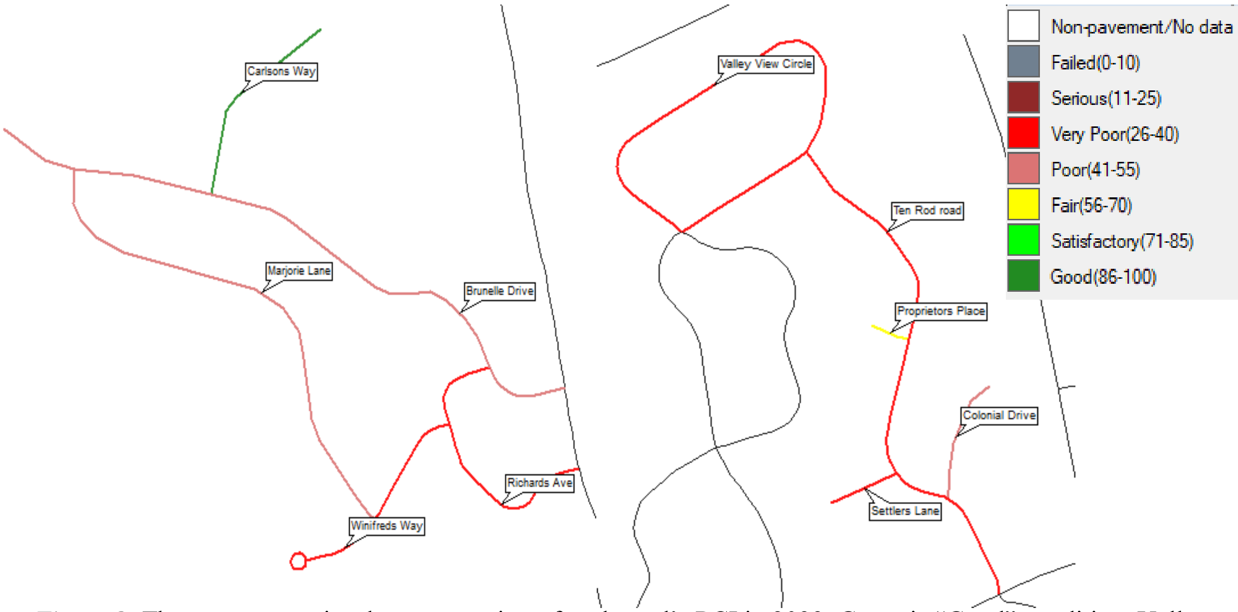


Figure 3: The maps are a visual representation of each road's PCI in 2033. Green is "Good" condition, Yellow is "Fair" condition, Light Red is "Poor" condition, Bright Red is "Very Poor" condition.

Another important capability included in PAVER is the Maintenance and Repair (M&R) planning. This feature allows the user to input a budget and a target PCI then the software will generate a repair plan for the selected roadways. The repair plan consists of three different types of M&R; preventative (above critical condition, examples: crack sealing, fog sealing, pothole filling. etc…), stopgap (below critical condition, examples: crack sealing, fog sealing, pothole filling, etc…), and major (failure condition, examples: new construction, mill and overlay, etc..). Included in the plans are year by year work summary for each roadway and also a yearly expenditure summary.

This feature could be beneficial for municipalities because it allows for the user to adjust the budget and see what works best for the given situation. The team decided to run three scenarios on the surveyed roads in Rutland over the next 5 years. Scenario 1, the team decided to execute a M&R plan with a goal to maintain the network PCI of 65.42 (+/- 3). PAVER suggested a work plan with a total cost of $285,000 to maintain the current PCI over the next 5 years (Attachment A). Scenario 2, the team executed a M&R plan with the goal PCI of 70 (+/- 3). This goal PCI was selected to place the roads in or near satisfactory condition. PAVER suggested a work plan with a total cost of $405,000 to achieve a PCI of 70 (+/- 3) over the next 5 years (Attachment B). Scenario 3, the team executed an M&R plan with the goal PCI of 85 (+/- 3). This goal PCI was selected to place the roads in or near good condition. PAVER suggested a work plan with a total cost of $775,000 to achieve a PCI of 85 (+/- 3) over the next 5 years (Attachment C).

Table 1 displays the cost summary of each M&R plan for the surveyed 2.56 miles of road.

Category	Total	2019	2020	2021	2022	2023
Scenario 1 (Maintain PCI)	$284,743	$51,486	$20,273	$88,910	$104,649	$19,422
Scenario 2 (Goal PCI 70)	$403,492	$51,486	$20,273	$88,910	$104,649	$138,172
Scenario 3 (Goal PCI 85)	$774,415	$51,486	$20,273	$251,694	$240,196	$210,763

This feature allows you to prevent road failure, avoiding full-depth reclamation which is a significantly more expensive repair. Based on the square yardage of all the surveyed roadways (38,100 yds^2) the full-depth reclamation total cost was estimated to $950,000. The three scenarios presented all demonstrate the ability of the software to cost-effectively spend a budget and develop a repair schedule. This feature in PAVER could aide in pavement management and budgeting.

Conclusion

The project team is confident in the recommendation of the pavement management software, PAVER to the town of Rutland, Massachusetts. The software's extensive capabilities as well as its competitive initial cost make it a viable option for the DPW.

Moving forward, the team advises that Mr. Joseph Buckley, Director of the Public Works Department takes the software recommendation made in this memorandum into consideration. Establishing a long-term plan for the road network will only improve the community and the quality of life of the residents in Rutland, Massachusetts. This memorandum will be accompanied by a full report that contains more detailed information regarding the project. The full report will be available at the conclusion of the project no later than March 10, 2019.

Pavement Management Major Qualifying Project Team
Worcester Polytechnic Institute
February 22, 2019

Attachment A: Scenario 1 Work Summary Chart

Road	2019	2020	2021	2022	2023	2024
Winifred's Way	Preventive + (SS-CT) Surface Seal - Coal Tar $7029.39 Before:61.45 After:65.6	Preventive $3803.01 Before:63.59 After:63.72	Preventive $4672.78 Before:61.71 After:61.84	Major Below Critical $77763.24 Before:59.83 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94
Marjorie Lane	Preventive + (SS-CT) Surface Seal - Coal Tar $7769.26 Before:69.56 After:72.83	Preventive $2301.44 Before:71.24 After:71.32	Preventive $2844.77 Before:69.73 After:69.81	Preventive $4149.9 Before:68.23 After:68.31	Preventive $5539.08 Before:66.72 After:66.8	Do Nothing Before:65.22 After:65.22
Richard's Avenue	StopGap $275.86 Before:58.41 After:58.41	StopGap $284.13 Before:56.24 After:56.24	StopGap $292.66 Before:54.06 After:54.06	StopGap $301.44 Before:51.89 After:51.89	StopGap $319.14 Before:49.72 After:49.72	Do Nothing Before:47.55 After:47.55
Carlson's Way	(SS-CT) Surface Seal - Coal Tar $2027.27 Before:96.96 After:97.27	Do Nothing Before:97.12 After:97.12	Do Nothing Before:96.96 After:96.96	Do Nothing Before:96.8 After:96.8	Do Nothing Before:96.64 After:96.64	Do Nothing Before:96.48 After:96.48
Brunelle Drive	Preventive + (SS-CT) Surface Seal - Coal Tar $15139.09 Before:67.54 After:71.01	Preventive $5022.58 Before:69.32 After:69.41	Preventive $7248.15 Before:67.71 After:67.81	Preventive $9589.58 Before:66.11 After:66.2	Preventive $12065.82 Before:64.51 After:64.6	Do Nothing Before:62.91 After:62.91
Valley View Circle	StopGap $523.01 Before:58.41 After:58.41	StopGap $538.7 Before:56.24 After:56.24	StopGap $554.86 Before:54.06 After:54.06	StopGap $571.51 Before:51.89 After:51.89	StopGap $605.06 Before:49.72 After:49.72	Do Nothing Before:47.55 After:47.55
Tenrod Road	Preventive + (SS-CT) Surface Seal - Coal Tar $15562.45 Before:62.46 After:66.5	Preventive $8036.17 Before:64.54 After:64.66	Preventive $10008.73 Before:62.7 After:62.82	Preventive $12093.01 Before:60.86 After:60.98	StopGap $665.5 Before:59.02 After:59.02	Do Nothing Before:57.06 After:57.06
Settlers Lane	StopGap $69.75 Before:58.41 After:58.41	StopGap $71.84 Before:56.24 After:56.24	Major Below Critical $25123.66 Before:54.06 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91 After:91
Proprietors Place	Preventive + (SS-CT) Surface Seal - Coal Tar $992.33 Before:78.7 After:80.95	Preventive $94.38 Before:79.84 After:79.88	Preventive $136.35 Before:78.77 After:78.81	Preventive $180.67 Before:77.7 After:77.73	Preventive $227.97 Before:76.62 After:76.66	Do Nothing Before:75.55 After:75.55
Colonial Drive	Preventive $2098.4 Before:61.45 After:61.58	StopGap $121.21 Before:59.57 After:59.57	Major Below Critical $38028.74 Before:57.55 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91 After:91

Attachment B: Scenario 2 Work Summary Chart

Road	2019	2020	2021	2022	2023	2024
Winifred's Way	Preventive + (SS-CT) Surface Seal - Coal Tar $7029.39 Before:61.45 After:65.6	Preventive $3803.01 Before:63.59 After:63.72	Preventive $4672.78 Before:61.71 After:61.84	Major Below Critical $77763.24 Before:59.83 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94
Marjorie Lane	Preventive + (SS-CT) Surface Seal - Coal Tar $7769.26 Before:69.56 After:72.83	Preventive $2301.44 Before:71.24 After:71.32	Preventive $2844.77 Before:69.73 After:69.81	Preventive $4149.9 Before:68.23 After:68.31	Preventive $5539.08 Before:66.72 After:66.8	Do Nothing Before:65.22 After:65.22
Richard's Avenue	StopGap $275.86 Before:58.41 After:58.41	StopGap $284.13 Before:56.24 After:56.24	StopGap $292.66 Before:54.06 After:54.06	StopGap $301.44 Before:51.89 After:51.89	Major Below Critical $119068.99 Before:49.72 After:100	Do Nothing Before:97 After:97
Carlson's Way	(SS-CT) Surface Seal - Coal Tar $2027.27 Before:96.96 After:97.27	Do Nothing Before:97.12 After:97.12	Do Nothing Before:96.96 After:96.96	Do Nothing Before:96.8 After:96.8	Do Nothing Before:96.64 After:96.64	Do Nothing Before:96.48 After:96.48
Brunelle Drive	Preventive + (SS-CT) Surface Seal - Coal Tar $15139.09 Before:67.54 After:71.01	Preventive $5022.58 Before:69.32 After:69.41	Preventive $7248.15 Before:67.71 After:67.81	Preventive $9589.58 Before:66.11 After:66.2	Preventive $12065.82 Before:64.51 After:64.6	Do Nothing Before:62.91 After:62.91
Valley View Circle	StopGap $523.01 Before:58.41 After:58.41	StopGap $538.7 Before:56.24 After:56.24	StopGap $554.86 Before:54.06 After:54.06	StopGap $571.51 Before:51.89 After:51.89	StopGap $605.06 Before:49.72 After:49.72	Do Nothing Before:47.55 After:47.55
Tenrod Road	Preventive + (SS-CT) Surface Seal - Coal Tar $15562.45 Before:62.46 After:66.5	Preventive $8036.17 Before:64.54 After:64.66	Preventive $10008.73 Before:62.7 After:62.82	Preventive $12093.01 Before:60.86 After:60.98	StopGap $665.5 Before:59.02 After:59.02	Do Nothing Before:57.06 After:57.06
Settlers Lane	StopGap $69.75 Before:58.41 After:58.41	StopGap $71.84 Before:56.24 After:56.24	Major Below Critical $25123.66 Before:54.06 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91 After:91
Proprietors Place	Preventive + (SS-CT) Surface Seal - Coal Tar $992.33 Before:78.7 After:80.95	Preventive $94.38 Before:79.84 After:79.88	Preventive $136.35 Before:78.77 After:78.81	Preventive $180.67 Before:77.7 After:77.73	Preventive $227.97 Before:76.62 After:76.66	Do Nothing Before:75.55 After:75.55
Colonial Drive	Preventive $2098.4 Before:61.45 After:61.58	StopGap $121.21 Before:59.57 After:59.57	Major Below Critical $38028.74 Before:57.55 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91 After:91

Attachment C: Scenario 3 Work Summary Chart

Road	2019	2020	2021	2022	2023	2024
Winifred's Way	Preventive + (SS-CT) Surface Seal - Coal Tar $7029.39 Before:61.45 After:65.6	Preventive $3803.01 Before:63.59 After:63.72	Preventive $4672.78 Before:61.71 After:61.84	Major Below Critical $77763.24 Before:59.83 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94
Marjorie Lane	Preventive + (SS-CT) Surface Seal - Coal Tar $7769.26 Before:69.56 After:72.83	Preventive $2301.44 Before:71.24 After:71.32	Preventive $2844.77 Before:69.73 After:69.81	Preventive $4149.9 Before:68.23 After:68.31	Preventive $5539.08 Before:66.72 After:66.8	Do Nothing Before:65.22 After:65.22
Richard's Avenue	StopGap $275.86 Before:58.41 After:58.41	StopGap $284.13 Before:56.24 After:56.24	StopGap $292.66 Before:54.06 After:54.06	Major Below Critical $108888.39 Before:51.89 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94
Carlson's Way	(SS-CT) Surface Seal - Coal Tar $2027.27 Before:96.96 After:97.27	Do Nothing Before:97.12 After:97.12	Do Nothing Before:96.96 After:96.96	Do Nothing Before:96.8 After:96.8	Do Nothing Before:96.64 After:96.64	Do Nothing Before:96.48 After:96.48
Brunelle Drive	Preventive + (SS-CT) Surface Seal - Coal Tar $15139.09 Before:67.54 After:71.01	Preventive $5022.58 Before:69.32 After:69.41	Preventive $7248.15 Before:67.71 After:67.81	Preventive $9589.58 Before:66.11 After:66.2	Preventive $12065.82 Before:64.51 After:64.6	Do Nothing Before:62.91 After:62.91
Valley View Circle	StopGap $523.01 Before:58.41 After:58.41	StopGap $538.7 Before:56.24 After:56.24	Major Below Critical $188388.28 Before:54.06 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91.01 After:91.01
Tenrod Road	Preventive + (SS-CT) Surface Seal - Coal Tar $15562.45 Before:62.46 After:66.5	Preventive $8036.17 Before:64.54 After:64.66	Preventive $10008.73 Before:62.7 After:62.82	Preventive $12093.01 Before:60.86 After:60.98	Major Below Critical $192930.93 Before:59.02 After:100	Do Nothing Before:97 After:97
Settlers Lane	StopGap $69.75 Before:58.41 After:58.41	StopGap $71.84 Before:56.24 After:56.24	StopGap $74 Before:54.06 After:54.06	Major Below Critical $27531.9 Before:51.89 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94
Proprietors Place	Preventive + (SS-CT) Surface Seal - Coal Tar $992.33 Before:78.7 After:80.95	Preventive $94.38 Before:79.84 After:79.88	Preventive $136.35 Before:78.77 After:78.81	Preventive $180.67 Before:77.7 After:77.73	Preventive $227.97 Before:76.62 After:76.66	Do Nothing Before:75.55 After:75.55
Colonial Drive	Preventive $2098.4 Before:61.45 After:61.58	StopGap $121.21 Before:59.57 After:59.57	Major Below Critical $38028.74 Before:57.55 After:100	Do Nothing Before:97 After:97	Do Nothing Before:94 After:94	Do Nothing Before:91.01 After:91.01